

Running head: EXTENDING THE ISE BEYOND SERIAL RECALL

Extending the Irrelevant Sound Effect beyond Serial Recall

By

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Abstract

The finding that serial recall performance for visually presented items is impaired by concurrently presented speech or sounds is referred to as the *irrelevant sound effect* (ISE). The foremost explanation for the effect is based on interference with rehearsal and seriation processes. The present series of experiments demonstrates that neither rehearsal nor seriation processes is necessary to observe the ISE. Evidence comes from three experiments that a) allow participants to report to-be-remembered items in any order, b) eliminate rehearsal by engaging participants in a cover task and surprising them with a memory test, and c) show that surprise non-serial recognition is immune to rehearsal-based experimental manipulations that modulate the ISE in more typical serial recall tasks. Together, the results show that models that rely on rehearsal or seriation processes to account for the ISE need to be reconsidered. Results are discussed in terms of interference with encoding of to-be-remembered material.

TABLE OF CONTENTS

ABSTRACT.....	II
TABLE OF CONTENTS	III
LIST OF TABLES	V
LIST OF FIGURES	VI
LIST OF APPENDICES	VIII
LIST OF ABBREVIATIONS	IX
Selective Attention	2
Attention Capture	4
The Irrelevant Speech/Sound Effect	8
The Serial Position Curve and the ISE.....	11
Models of the ISE.....	15
Challenges to the Importance of Serial Rehearsal	20
The Present Study.....	24
Summary of Experiments.....	26
EXPERIMENT 1	32
Methods.....	33
Participants.	33
Materials.	33
Design.....	35
Procedure.....	35
Results.....	36
Lexical decision task.	36
Response time.	36
Accuracy.	37
Recognition memory performance.	39
Discussion	40
EXPERIMENT 2	42
Methods.....	43
Participants	43
Materials	44
Design.....	44
Procedure.....	46
Results.....	47
Lexical decision task.	47
Response time	47
Accuracy	49
Memory performance.	50
Surprise non-serial recognition	50
Serial recall (conservative scoring method).....	53
Serial recall (scoring without order constraints).....	54
Discussion	56
Surprise non-serial recognition & changing- versus steady-state	57

Serial recall	61
EXPERIMENT 3	65
Method	66
Participants	66
Materials	66
Design	67
Procedure	68
Results	70
Lexical decision task	70
Response time.	70
Accuracy	71
Memory performance.	72
Surprise non-serial recognition.	72
Serial recall (conservative scoring method).....	74
Serial recall (scoring without order constraints).	76
Summary of planned comparisons.	78
Discussion	79
GENERAL DISCUSSION	82
Implications for Models of the ISE	83
Attentional Distraction and Lexical Decision Performance.....	88
Disambiguating Identity and Order Information in Serial Recall	89
Implications for our Understanding of Bottom-up and Top-Down Processing	91
Serial Position Curves	93
Final Summary	95
REFERENCES.....	96
APPENDIX A	102
APPENDIX B	103
APPENDIX C	105
APPENDIX D	109

List of Tables

- Table 1. Mean (Standard Deviation) memory performance for each task and measure as a function of sound condition: changing-state (CS) or silence (SIL), and concurrent articulation (CA) or no CA (NA).

List of Figures

- Figure 1. Mean probability of recall as a function of background condition and serial position; Speech = irrelevant foreign speech. Figure adapted from Colle and Welsh (1976, Experiment 1).
- Figure 2. Mean Lexical Decision RTs in Experiment 1 as a function of lexical status and irrelevant sound condition. Error bars represent standard error for each mean.
- Figure 3. Mean Proportion Correct Lexical Decisions in Experiment 1 as a function of lexical status and irrelevant sound condition. Error bars represent standard error for each mean.
- Figure 4. Mean Lexical Decision RTs in Experiment 2 as a function of lexical status and irrelevant sound condition. Error bars represent standard error for each mean.
- Figure 5. Mean Proportion Correct Lexical Decisions in Experiment 2 as a function of lexical status and irrelevant sound condition. Error bars represent the standard error for each mean.
- Figure 6. Memory performance on the surprise recognition memory test based on words presented in Lexical Decision task in Experiment 2. A) Mean sensitivity scores (hits-false alarms) for words as a function of sound condition. B) Mean probability of recognition as a function of sound condition and serial position in the Lexical Decision task.
- Figure 7. Memory performance in the serial recall task of Experiment 2. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition and serial position. Columns represent mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL), steady-state irrelevant sound (SS), and changing-state irrelevant sound (CS) averaged across serial positions. Error bars represent standard error for each mean.
- Figure 8. Memory performance in the serial recall task in Experiment 2 scored without regard for recall order. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition and serial position. Columns represent overall mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL), steady-state irrelevant sound (SS), and changing-state irrelevant sound (CS), collapsed across serial position. Error bars represent standard error for each mean.

- Figure 9. Mean Lexical Decision RTs in Experiment 3 as a function of lexical status, irrelevant sound condition and presence/absence of CA. Error bars represent the standard error for each mean.
- Figure 10. Mean Proportion Correct Lexical Decisions in Experiment 3 as a function of lexical status, sound condition and presence/absence of CA. Error bars represent the standard error for each mean.
- Figure 11. Memory performance on the surprise recognition memory test in Experiment 3. Lines represent mean probability of recognition as a function of sound condition, CA and serial position. Columns represent mean sensitivity scores for words as a function of irrelevant sound condition: silence (SIL) and changing-state irrelevant sound (CS); and concurrent articulation (CA) and no CA (NA). Error bars represent the standard error for each mean.
- Figure 12. Memory performance in the serial recall task of Experiment 3. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition, CA and serial position. Columns represent mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL) and changing-state irrelevant sound (CS); and concurrent articulation (CA) and no CA (NA). Error bars represent the standard error for each mean.
- Figure 13. Memory performance in the serial recall task in Experiment 3 scored without regard for recall order. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition, CA and serial position. Columns represent overall mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL) and changing-state irrelevant sound (CS); and concurrent articulation (CA) versus no CA (NA). Error bars represent the standard error for each mean.

List of Appendices

Appendix A	Research ethics board letter of approval
Appendix B	Consent form
Appendix C	Pool of words used in non-serial recognition and serial recall tasks
Appendix D	Pool of pseudo-words used in non-serial recognition task

List of Abbreviations

CA	Concurrent Articulation
CS	Changing-state
dB	Decibels
ISE	Irrelevant Sound Effect
ISI	Inter-Stimulus Interval
NA	No Articulation
O-OER	Object-Oriented Episodic Record
RT	Response Time
SIL	Silence
SS	Steady-state
SPL	Sound Pressure Level

Extending the Irrelevant Sound Effect beyond Serial Recall

Selective Attention

The world is a vast and overwhelming place at times — packed with more information than an individual could ever hope to process. As such, it is vital to human existence that this cacophony of input is whittled down so that only the most relevant information is processed for awareness and memory. The memory encoding process begins with the ability to attend to specific pieces of information while ignoring or suppressing other, irrelevant, input (Mangels, Picton, & Craik, 2001). For early psychological researchers, theories of attention were understood intuitively. For example, psychologist William James (1890) writes, “Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought.” (p. 403). More recent investigations into the nature of attention have, however, revealed that this seemingly simple process is considerably more complex.

Broadbent (1958) proposed one of the first influential models of selective attention. He suggested that an attentional filter sits between sensory input and the mechanism by which information is attended such that it can be added to memory. This early filter selects relevant information from amongst irrelevant information according to its physical properties (e.g., loudness, pitch, or timbre) before any information is semantically processed. In this way, Broadbent’s filter model for selective attention is labelled as an *early selection* theory of selective attention. That is, information is filtered

and sorted early in the information processing system, prior to being processed for meaning.

This early selection model was supported by results from dichotic listening tasks (Cherry, 1953). In this task, participants wore headphones and were presented with two simultaneous, but different, speech messages: one in each ear. Participants were instructed to pay attention to the message in only one ear and shadow its contents (i.e. repeat verbally the information as it plays). When questioned afterwards, participants were not able to recall any of the content that was presented in the unattended ear. Furthermore, they did not detect changes in the semantic content or the language that was spoken in the message from the unattended ear. However, they were able to describe the physical properties of the voice and any changes in these properties: whether the voice was male or female, pacing, or how loud it was (Cherry, 1953). The fact that participants were able to identify the physical properties, but not the semantic meaning, of the unattended message supported Broadbent's (1958) early selection filter model perfectly.

Further evidence from dichotic listening experiments required an amendment to Broadbent's (1958) all-or-none early filter model for selective attention, as it was observed that semantically relevant stimuli could bypass the filter mechanism even when presented in the unattended speech channel. Moray's (1959) experiment (later extended by Wood and Cowan, 1995) revealed that a participant's own name could sometimes be processed for meaning and reach conscious awareness when presented in an unattended auditory channel. This so-called "cocktail party phenomenon" illustrates how personally

salient stimuli can capture attention from amongst other unattended stimuli. Treisman (1960) was also able to show that if the semantic content of the unattended message was similar to the content of the shadowed message, then shadowing was impaired compared to when a semantically unrelated message was presented in the unattended ear. In response to these new data, Treisman (1960, 1964) suggested that to-be-ignored stimuli were simply attenuated rather than filtered out completely prior to semantic analysis; therefore, stimuli that were particularly relevant semantically could still break through into awareness. That is, an unattended stimulus could still reach consciousness if that stimulus was semantically relevant to the listener and its activation was high enough to survive attenuation by the filter. Thus according to Treisman's theory of selective attention, participants should be able to ignore easily all but personal or task-relevant unattended stimuli. However, Deutsch and Deutsch (1963) argued that a physical property filter *and* a semantic processing attenuation filter in the same model were redundant, and suggested that both physical and semantic information is used by the filter. Deutsch and Deutsch further specified that only the representations with the greatest activation actually reach consciousness and become available for further processing. In this way, Deutsch and Deutsch (1963) provided a *late selection* theory of selective attention: stimuli are selected for awareness only after being processed for meaning.

Attention Capture

In typical daily activity, it is important to attend to specific stimuli while ignoring other irrelevant stimuli. For example, while driving, it is important to focus on avoiding

obstacles and maintaining a predictable velocity despite distracting conversation in the car or music on the radio. However, it is also important to remain distractible to a certain level. For example, a honking horn, or a change in the sounds emitted by the vehicle may indicate imminent danger. Thus, preserving some degree of distractibility may frequently operate as a protective mechanism. The late selection model proposed by Deutsch and Deutsch (1963) would suggest that sounds such as car horns, engine noise, or emergency vehicle sirens can be permitted access to consciousness as they are semantically bound to the context of driving a car. Indeed, shifts of attention can be observed when the distracting stimulus (e.g., a car horn) is semantically associated with, and relevant to, the primary task. However, shifts of attention can also occur even when the distracting stimulus is not relevant to the primary task (Lange, 2005; Schröger & Wolff, 1998; for a review see Lavie, 2005). Returning to the example of driving a car, an attractive member of the opposite sex passing by or a flashy billboard near a shopping centre can distract a driver, making an accident more probable. Neither of these irrelevant stimuli is directly related to the task of driving, yet they are still permitted to enter into consciousness and draw on attentional resources. Clearly, not all shifts of attention are adaptive or beneficial to an individual.

What is clear from attention studies, and daily experience, is that selective attention may be characterized as a competition between bottom-up and top-down processes. Bottom-up processes, driven by featural stimulus information, are thought to operate independent of a perceiver's expectations. Posner and Raichle (1994) argued that bottom-up processes can be defined in terms of automatic processing of information even

when attentional resources are not invested in their observation. Certain types of stimulus information can reliably capture an individual's attention in a bottom-up manner. For example, research has shown that transients such as rapid onsets, rapid offsets, movement or colour can attract attention, as can certain types of novelty within a scene (Breitmeyer & Ganz, 1976; Müller & Rabbitt, 1989; Theeuwes, Kramer, Hahn, & Irwin, 1998). Curiously, bottom-up attention capture is not limited to purely low-level information. Indeed, some semantic content can also capture attention in a bottom-up way that does not depend on context or task goals. For example, one's own name or emotionally arousing words (Arnell, Killman, & Fijavz, 2007) or pictures (Most, Chun, Widders, & Zald, 2005) can automatically capture attention leading to increased response time or accuracy costs in dual task paradigms. In contrast with bottom-up processes, top-down processes are driven by a perceiver's goals or prior concepts. Indeed, researchers have observed what has come to be referred to as "contingent capture", where irrelevant stimuli can capture attention away from a primary task only if the capture feature is relevant for the target task at hand (Folk, Remington & Johnston, 1992). In the context of distraction, a perceiver's top-down goal might be to inhibit irrelevant information while performing a primary task (e.g., ignore an attractive billboard advertisement while driving). However, because a bottom-up flow of attention must be maintained to allow the perception of potentially hazardous irrelevant material (e.g., a change in the sound emitted by the vehicle's engine), a balance must be struck between inhibiting all irrelevant information to stay focused on a primary task and permitting access to some task-irrelevant material if it signals something of importance.

Bottom-up attention capture has not only been shown to result in deficits on a concurrent attention demanding task, but has also been shown to impair later memory performance. For example, in Lange's (2005) study, participants were told to passively observe the digits 1 to 9 as they were randomly presented on a computer screen for later serial recall. Synchronously presented with the onset of each to-be-remembered visual item, an auditory tone was played through headphones. The irrelevant auditory stream was characterized by a single repeated 500ms tone. Sometimes, however, the repeated tone was replaced with a tone of a different pitch which then repeated (note how this procedure mimics the scenario described above where a change in the sound of a vehicle's engine may signal danger). When the unpredictable tone change occurred, memory for the temporally proximal visual to-be-remembered item was impaired relative to memory for visual items presented with the repeated tone. Following Cowan's (1995) memory model, Lange (2005) suggested that the internal representations of the to-be-remembered visual material are held in the focus of attention. When there is a change in the physical properties of the irrelevant auditory stream (e.g., change in pitch), attention is involuntarily and automatically captured in a bottom-up manner away from the primary task.

Using various forms of relevant and irrelevant material, other researchers have also shown that a single irrelevant auditory deviant can capture attention and impair serial recall performance for visual items (Hughes et al., 2005; Hughes, Vachon, & Jones, 2007; Lange, 2005). For example, Hughes and colleagues (2005) observed serial recall deficits when to-be-remembered visual consonants were paired with irrelevant auditory

digit streams that contained a temporal deviant, versus auditory streams with a constant inter-stimulus interval. This same pattern of impaired serial recall performance was observed when the irrelevant auditory deviant was a single item voiced by a male embedded within a stream of items voiced by a female (Hughes et al., 2007). During processing of the auditory deviant, relevant visual items that are currently held in the focus of attention lose their activation benefit and the encoding process is perturbed. In this way, the item cannot be effectively consolidated and is poorly represented by the time of serial recall. That these effects are observed even when the physical change occurs in a to-be-ignored modality suggests that despite top-down exertion of control, some degree of bottom-up obligatory auditory processing nonetheless occurs (Hughes et al., 2005). This so-called *Deviation Effect*, defined as attention capture by a deviant irrelevant item, is thought to be distinct from a more well-known finding where even ongoing irrelevant auditory material reduces memory performance for visual items, relative to silence —the *Irrelevant Sound Effect* (Hughes et al., 2005, 2007).

The Irrelevant Speech/Sound Effect

Early studies designed to investigate the effect of irrelevant distractors on memory performance in controlled laboratory settings, revealed what is known as the *Irrelevant Speech Effect* (Colle & Welsh, 1976). The prototypical Irrelevant Speech Effect study requires participants to attend to short lists of visually presented items (typically digits or words) under conditions of silence or with concurrent irrelevant speech. Colle and Welsh (1976) were the first to demonstrate that concurrent presentation of irrelevant (to-be-ignored) speech impaired immediate serial recall of visually presented verbal material. In

their original study, participants were presented with lists of eight visual consonants, ordered randomly and displayed one at a time. The irrelevant speech, presented throughout the entire task, was a passage from Franz Kafka's *A Hunger Artist* spoken in German—a language foreign to all participants in the study. Participants showed lower serial recall scores for consonants presented during irrelevant speech compared to the serial recall scores for consonants presented during silence. Since that first demonstration, the irrelevant speech effect has been observed with various to-be-remembered items such as consonants, digits, or words. Although the irrelevant speech effect is typically observed using a cross-modal paradigm where target stimuli are presented visually and the irrelevant sound is presented auditorily (e.g., Beaman & Jones, 1997; Colle & Welsh, 1976; Jones, 1993; Jones & Macken, 1993, 1995; LeCompte, 1994), the effect can also be found when target items are presented auditorily in a procedure similar to a dichotic listening task (e.g., Hanley & Broadbent, 1987; LeCompte, 1996; Schlittmeier, Hellbrück, & Klatte, 2008). The effect is not limited to irrelevant speech as it is also observed when the irrelevant sound is comprised of auditory tones (Beaman & Jones, 1993; Jones & Macken, 1993; Macken, Tremblay, Houghton, Nicholls, & Jones, 2003) or music (Ellermeier & Hellbrück, 1998; Morris, Jones, & Quayle, 1989; Nittono, 1997; Salamé & Baddeley, 1989; Schlittmeier, Hellbrück, & Klatte, 2008). Thus, the term *irrelevant speech effect* is somewhat of a misnomer. Therefore, the effect is now more commonly referred to as the *irrelevant sound effect* (ISE).

The ISE is quite large in magnitude and is a robust effect, easily observed in most participants. It is typical to observe memory performance impairment associated with irrelevant speech of approximately 8% (e.g., Ellermeier & Zimmer, 1997) to 12% (Colle & Welsh, 1976) compared to a silent control condition. Additionally, the effect is known to be extremely stable within individuals both within and between experimental sessions. Individuals consistently show a reliable degree of irrelevant sound disruption over several weeks (test-re-test correlation of .45; Ellermeier & Zimmer, 1997).

Interestingly, the ISE is not as pronounced when the irrelevant sound is comprised of white/pink noise (LeCompte, 1994) or a repeated single tone (Jones et al., 1992), compared to speech, music, or auditory tones that vary unpredictably in pitch (Beaman & Jones, 1997). White noise (a sound containing all auditory frequencies) and pink noise (a sound containing predominantly mid-range frequencies) are constant and fixed (steady-state; discussed later) sound profiles with equal sound intensities at all frequencies (pitches). Imagine the sound a TV makes when no signal is detected and the black and white “snow screen” is displayed. Thus, irrelevant sounds appear to result in an ISE only when they are perpetually changing according to some acoustic property. The only known changing-state acoustic property that is not associated with irrelevant sound disruption is sound pressure level (Ellermeier & Hellbrück, 1998; Jones, Miles, & Page, 1990). That is, in an otherwise steady-state stream of irrelevant auditory items, random changes in perceived volume will not elicit the effects observed with stimuli that change based on other acoustic properties.

Currently, the most potent form of irrelevant sound is speech. According to Jones and Macken (1993; 1995), this may be due to the fact that speech contains significantly more (abrupt) changes than any other form of irrelevant sound. Jones and Macken (1993; 1995; see also Jones, Madden, & Miles, 1992) demonstrated that *changing-state* irrelevant stimuli (e.g., a sequence of sounds comprised of different stimuli) are significantly more disruptive to serial recall than *steady-state* irrelevant stimuli (e.g., a single tone repeated at regular temporal intervals). Even when presented at a constant rate, sound sequences are classified as “changing-state” as long as each successive item is different from the preceding item in at least one aspect (e.g., pitch or timbre). Speech contains a considerable amount of changes, so it is generally regarded as the most potent form of irrelevant sound.

The Serial Position Curve and the ISE

One of the most well-known aspects of performance on serial recall tasks used to investigate the ISE is its dependency on the serial position of a given item within the list of to-be-remembered items. This so-called *serial position effect*, originally documented by Ebbinghaus (1902 as cited in Robinson & Brown, 1926) describes simply how a given item’s relative position in a list of to-be-remembered items dictates its likelihood of recall. Serial recall in general usually produces a large primacy effect; that is, increased accuracy for items that lie at the beginning of the list. Accuracy steadily declines towards the latter part of the list, but there is often a small recency effect where accuracy improves for the last few items (Jahnke, 1963). Greater recency effects are observed in free versus serial recall paradigms where participants are permitted to report the items in

any order (Deese, 1957; Jahnke, 1965) given that under conditions of free recall participants begin by reporting the last few items that are still being rehearsed in working memory. This recency effect is also observed in non-serial recognition paradigms (e.g., LeCompte, 1994, Experiment 5A).

Primacy effects are thought to be driven by long-term storage strategies or some form of attentional gradient (Oberauer, 2003) where items at or near the beginning of a list benefit from greater dedication of attentional resources which monotonically decreases over time. Thus, list items that follow are gradually allotted fewer and fewer resources. The least resources are allotted to items that fall toward the end of the series and are thus relatively poorly recalled. However, these last few items typically benefit from short-term strategies, distinctiveness, or immediate activation which leads to recency effects. Retroactive interference may also drive recency effects (Oberauer, 2003) where representations for the most recently encoded or retrieved items are “superimposed” on temporally distant representations (e.g., items earlier in the sequence).

To-be-remembered list length also plays a relatively important role in serial position effects. For example, in serial and free recall tasks, recency effects become greater relative to primacy effects, as list length increases from six items to 15 items (Jahnke, 1965). However, given that recency effects are thought to be driven by rehearsal, and that short lists (e.g., 4-10 items) versus long lists (16 items) tend to encourage a rote serial rehearsal strategy (Beaman & Jones, 1997), a relatively strong recency effect should be observed in a standard free recall task for lists of any length.

Does the presence of irrelevant sound impair serial recall performance at some list positions more than others? Across a number of ISE studies, the data from serial position curves suggest that when the primary task is based strictly on serial recall, memory for items at position 1 is relatively unharmed by irrelevant speech or sounds. Memory disruption due to irrelevant sound becomes apparent for mid and latter portions of the presentation list, and, despite a small overall recency effect, disruption due to irrelevant sound is still observed for the last list position (see Figure 1 for an example).

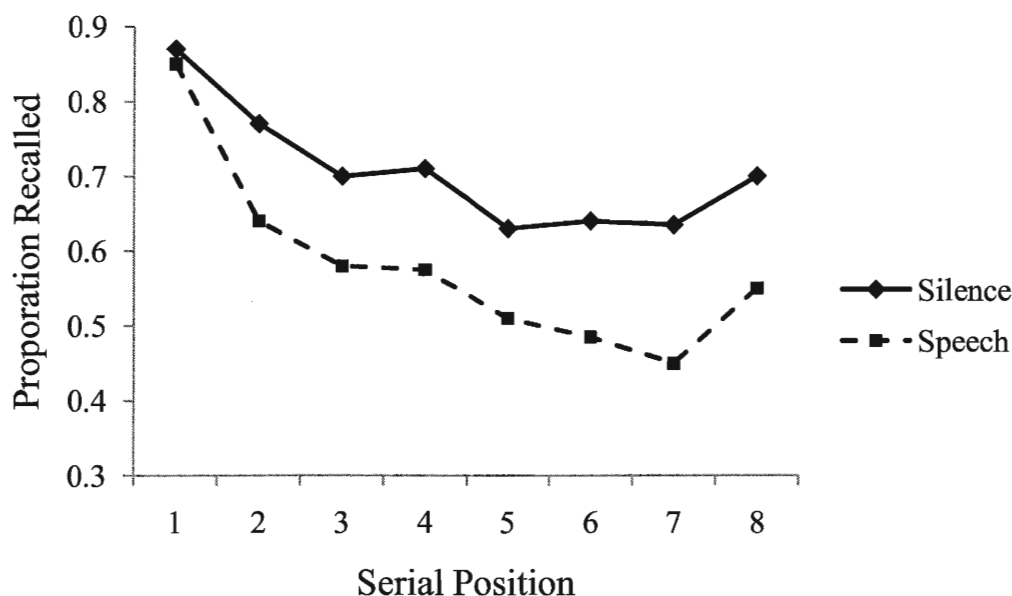


Figure 1. Mean probability of recall as a function of background condition and serial position; Speech = irrelevant foreign speech. Figure adapted from Colle and Welsh (1976, Experiment 1).

Although there are relatively few free recall ISE experiments that can be examined, it appears as if the ISE may show a different pattern across list positions when free recall is used as the primary task, as opposed to serial recall. LeCompte (1994,

Experiment 4) found a numerical difference between irrelevant sound conditions for items located in the first half of the 12-item list only; an ISE was not observed for the longer 16-item list. Overall, a very large recency effect was observed in this study, but latter positions showed no ISE. This pattern was also observed in Experiment 1 by LeCompte (1994), with the exception that there was a numerical accuracy advantage for silence versus sound in all but the last two serial positions (positions 11 and 12). The large recency effect in free recall is typically assumed to result from participants first reporting the list items that are actively being rehearsed at the time of recall. If this is true, then the absence of an ISE effect for latter stream positions in the free recall task of LeCompte (1994) provides speculative but suggestive evidence that rehearsal may be unimpaired by irrelevant sound.

Long list free recall tasks (e.g., 16 items), where participants passively view and verbally report to-be-remembered items, have been reported to have relative immunity to irrelevant sound (LeCompte, 1994; Salamé & Baddeley, 1990). Indeed, although an ISE was observed when the list length was 12 items long, it was not observed under otherwise comparable conditions when the list length was increased to 16 items (LeCompte, 1994; Experiment 4). The results of LeCompte (1994) mimic those of Salamé and Baddeley (1990) who failed to find an ISE using a free recall task with long 16-item lists. It is possible that 16-item to-be-remembered lists are too long to benefit much from a rote serial rehearsal strategy (aside from the recency effect), yet too short to promote the use of effective long-term strategies.

Interestingly, an ISE has been observed for 16 item lists, but only when a recognition task was used, not a free recall task. Both when the recognition memory test required a yes/no decision as to whether the word was on the study list, and when participants were asked to indicate which of two words was seen on the study list, accuracy was high and did not vary much as a function of serial position (LeCompte, 1994 Exp. 5B and 5C). However, memory performance was numerically better for words studied in the white noise control condition than for words studied with irrelevant speech at most serial positions.

Models of the ISE

Several models have been proposed to account for the ISE, and most of these have been influenced heavily by the use of serial recall as the primary task. One such example is the prominent model of the ISE—the Object-Oriented Episodic Record Model (O-OER; Jones, 1993). Critically, the O-OER model stresses that the memory impairment reflected in the ISE is based on the disruption of order information and serial rehearsal processes. Jones (1993) asserts that all stimuli, whether visual or auditory, automatically generate internally represented linkages, or pointers, that embody the order in which the to-be-remembered stimuli were presented. These linkages are maintained over time to preserve the order in which the items were presented and are subsequently referenced during retrieval. According to the O-OER model, these linkages are amodal in nature and are generated automatically by both relevant and irrelevant material. Because each source of information can produce linkages, relevant and irrelevant linkages may become confused with each other leading to perturbation of order

information for the relevant material. Therefore, the O-OER model explains the ISE in terms of order linkages generated by irrelevant material interfering with order linkages generated by relevant material.

As a corollary of the O-OER model, the so-called *changing-state hypothesis* (Jones & Macken, 1993; 1995) states that the degree to which the irrelevant sound changes in terms of physical and acoustic features is directly proportional to the amount of disruption in a serial recall task. The authors suggest that the seriation linkages or pointers that underlie the ISE in the O-OER model also underlie the relationship specified in the changing-state hypothesis. There are two factors in changing-state stimuli that are related to pointer generation. First, greater acoustic changes (e.g., disparity in auditory frequency or pitch of tones) are associated with greater cues to seriation. That is, if the perceptual difference between two successive tones is relatively large, it elicits a proportionally strong pointer. Similarly, the *quantity* of pointers generated is directly proportional to the number of acoustic changes in the auditory stream. Jones and Macken (1993; 1995) suggest that because changing-state stimuli generate more pointers than steady-state stimuli and are qualitatively more varied, they are thus more disruptive to serial recall because there are more opportunities for overlap of relevant and irrelevant linkages. According to the O-OER model and the changing-state hypothesis, any disruption associated with irrelevant sound should be observed only when participants rely on a strategy that specifically draws on the order information contained within these linkages.

Another, less prominent, model that could be used to account for the ISE is Cowan's (1995, 1999) embedded-processes model of working memory. This model suggests that the cognitive locus of distraction is the redirection of the focus of attention away from the primary stimuli or task. According to the model, working memory is hierarchically arranged. At the base are long-term memory stores which are not activated during the operation of working memory. These long-term memory representations remain out of consciousness until they are required or actively searched. Above the long-term memory stores is a subset of activated stores called short-term memory. These stores may be previous representations retrieved from long-term memory or recently added memory representations based on experience. These short-term stores are susceptible to time-based decay (typically 10 - 20 seconds). Finally, a subset of the short-term memory store is held in the much smaller focus of attention. Representations held in the focus of attention are consciously and immediately available for use in working memory. Although the focus of attention is consciously and voluntarily controlled by a central executive (c.f., Baddeley & Hitch, 1974), it can be involuntarily attracted by personally relevant stimuli (e.g., Moray, 1959; Treisman, 1960) or changes in physical properties of an irrelevant stream of stimuli (Berti & Schröger, 2001; Escera et al., 1998; Johnson & Zatorre, 2005; Lange, 2005; Schröger 1997; Schröger & Wolff, 1998; for a review see Driver, 2001). Thus, if the focus of attention is attracted away from the to-be-remembered items by irrelevant material, they will no longer be active in working memory. As a result, memory impairment should be observed.

Unlike the O-OER model (Jones, 1993), Cowan's (1995; 1999) embedded-processes model does not rely on a disruption of order information (e.g., seriation linkages) to explain the memory impairment associated with irrelevant sound. Note also that Cowan's model does not rely directly on a disruption of rehearsal processes to explain the ISE. Rather, the model suggests that items held in the focus of attention at the moment of distraction lose their activation benefit and are subsequently only weakly represented in short-term (and subsequently, long-term) memory.

Additionally, Cowan (1995, 2000) describes a rehearsal mechanism subordinate to the focus of attention which keeps to-be-remembered items accessible to the focus of attention. Over time, this rehearsal loop becomes automatic and attention is no longer needed. Cowan describes a scenario in which a participant may rehearse a portion of a to-be-remembered digit list while using the focus of attention to accomplish other portions of the task or to maintain the other items. Note that this notion may only apply when relatively short lists must be remembered. When long lists are used, an entirely different strategy based on relative activation level may be employed.

In sum, the model suggests that all incoming information receives some form of activation; items that enter the focus of attention receive the greatest benefit. Under conditions of distraction, where the focus of attention may be diverted by task-irrelevant material, target items lose their activation benefit and are only weakly represented in memory. Note that the focus of attention is also responsible for maintaining focus on the primary task. Thus, to the extent that the primary task involves the preservation of item information (e.g., for later recall), attention capture by irrelevant stimuli should reduce

memory performance even when rehearsal is not required. If the task is to simply “rehearse items for later recall”, then distraction by irrelevant sound may also show an additional cost given that rehearsal itself may also be interrupted. In this way, Cowan’s (1995) model can be used to explain the ISE in a serial recall task in terms of distraction from the task of rehearsal. However, in a scenario where rehearsal is not a central component of the task, attentional distraction from the primary task can still explain subsequent memory impairment via reduced activation and representation in working memory.

Earlier, Broadbent (1984) had suggested a different attentional model in which the ISE was said to result from a breakdown at an attention-demanding encoding stage where features of to-be-remembered items must be transformed into a conscious internal representation in working memory. According to Broadbent’s (1984) account, irrelevant sound/speech impairs the ability to convert to-be-remembered items into the phonological code—a short-term storage for audio-verbal items akin to working-memory. Target items that are presented auditorily are given automatic access to the short-term phonological store (e.g., Salamé & Baddeley, 1982). Incidental irrelevant speech or other changing-state auditory items are also given automatic access to this store. Consequently, these irrelevant items are able to disrupt articulation into memory of relevant to-be-remembered items. Using the language of articulation, however, may have implicitly directed other researchers to infer a rehearsal process, as this model has not been popular when discussing the ISE.

The feature model proposed by Nairne (1990) and extended by Neath (2000) posits that the ISE occurs at an earlier processing stage, and is due to interference between the *features* of relevant and irrelevant stimuli. To illustrate, imagine an LCD computer screen which is made up of thousands of distinct pixels. Further imagine that each pixel is either “on” or “off” (i.e., black or white). Individually viewing a single pixel (or feature) is meaningless, but when all the pixels are viewed in relation to each other, an image becomes apparent. In this way, a large proportion of individual pixels can be broken or distorted while still allowing a discernible image. The model suggests that distraction by irrelevant stimuli is a progressive occlusion of informative pixels until a point at which the overall image loses its integrity. Although this model provides a straightforward account of the ISE, Nairne’s (1990) model still relies on physical similarity between relevant and irrelevant stimuli and centres on interference with verbal or speech items by other verbal or speech items. In this way, the model is limited to a domain-specific locus of distraction in which the irrelevant stimuli must match the relevant stimuli across numerous physical properties. According to this model, irrelevant stimuli other than speech (e.g., changing-state tones) should not disrupt serial recall performance. In reality, the ISE has been observed with numerous non-speech sounds including tones (Jones & Macken, 1993). Thus, the feature model cannot readily account for the ISE.

Challenges to the Importance of Serial Rehearsal

The vast majority of experiments examining the ISE utilize procedures based on immediate serial recall tasks. Thus, it is perhaps not surprising that the dominant model

accounting for the ISE is based on interference of serial rehearsal processes. The first test of whether or not serial rehearsal was required to observe the ISE came from Salamé and Baddeley (1990) who examined the effect of irrelevant speech in an immediate free recall paradigm. In this paradigm, participants were permitted to report 16-item word-lists in any order they wished. Although participants showed a clear ISE in a standard 9-item serial digit recall task under the same irrelevant sound conditions, these same participants did not show an ISE in the novel free recall task. Perhaps as a consequence of these null results, subsequent ISE research tended to avoid non-serial recall tasks, and the O-OER model took precedence.

Using a within-subjects experimental design and significantly more participants (68 versus 24 in Salamé and Baddeley's 1990 experiment), LeCompte (1994) demonstrated that the ISE is not necessarily limited to tasks that require the maintenance of order information. In addition to demonstrating irrelevant sound interference in a standard serial recall task, LeCompte (1994) revealed a significant ISE in tasks of free recall and recognition. In a test of free recall, participants viewed letters on a computer screen at a rate of one per second under conditions of irrelevant speech, white noise, or silence. Participants were told to remember the letters for later recall, and to ignore any spoken words or sounds that they might hear through the headphones. One second after the presentation of the final item in each of the 12-item to-be-remembered lists, participants then recalled the letters in any order they wished. Results indicated that irrelevant speech impaired recall performance by approximately 5% compared to the silent control condition. Performance during white noise was not different from the silent

control condition. In a separate recognition task, participants viewed words presented one at a time in the presence of irrelevant speech or continuous steady-state white noise. During the test phase, participants viewed words one at a time and indicated whether each word was old (was shown in the study phase) or new (was not shown in the study phase). Results showed recognition memory impairment of approximately 10% for items presented during speech versus white noise. In a subsequent experiment, participants followed a similar procedure during the study phase. However, 500ms white noise bursts were used instead of a continuous stream of white noise. Additionally, the test phase consisted of a two-alternative forced-choice recognition memory test where participants reported which of two words had been presented in the study phase. Results indicated that, compared to the white noise control condition, irrelevant speech impaired non-serial recognition memory performance by approximately 6%. In the final experiment in the series, LeCompte (1994) had participants study pairs of words. At test, one word from the pair was presented and participants were asked to type the paired-associate from the study list. This paired-associate task also showed a small (3%) but significant ISE.

Although LeCompte's (1994) non-serial results may appear compelling in terms of ruling out serial rehearsal confusion as a basis for the ISE, it is important to note that, in all conditions, participants were fully aware that their memory for the visual items would be tested. Therefore, it is possible that at least some participants were employing a serial rehearsal strategy even though it was not explicitly required to complete the task. Thus, it is not clear whether the ISE was a result of interference with the rehearsal process or more directly with encoding of the to-be-remembered items. Despite the

possibility for rehearsal, LeCompte's (1994) results provided the first piece of evidence against the prevailing belief that irrelevant speech interferes with representations of order, as the ISE was observed even when order information was not necessary for the task.

After finding the ISE in several non-serial tasks (free recall, cued recall, and recognition) LeCompte (1994) argued that maintenance of order information was not necessary to find the effect. Instead, LeCompte proposed the adoption of Watkin's (1984, as cited in LeCompte, 1994) law of ascendancy which states that auditory stimuli have priority in short-term memory. Auditory material whether relevant or irrelevant will tend to impose itself over visually presented material or previously presented auditory material. Indeed, the law of auditory ascendancy predicts an ISE on any task that relies heavily on short-term memory and/or rehearsal.

Given that LeCompte's procedure informed participants of the impending memory test, participants may have nonetheless employed a rehearsal strategy that was serial in form. To examine this possibility, Beaman and Jones (1997) developed a series of experiments designed to replicate the approach used by LeCompte (1994) with one key distinction—participants were charged with the additional task of articulating a short series of letters throughout each set. This concurrent articulation (CA) is thought to suppress the process of serial rehearsal such that irrelevant speech/sound cannot additionally interfere with the rehearsal of to-be-remembered items (Beaman & Jones, 1997). That is, CA suppresses phonological articulation of to-be-remembered items such that they are not phonologically coded or rehearsed, or entered into the temporary phonological store leading to poor serial recall performance (Salamé & Baddeley, 1990).

When participants engaged in this additional CA task, the ISE disappeared. Note that CA also eliminates the ISE in the accepted serial recall task (see Baddeley, 1990b). Beaman and Jones (1997) argued that the ISE was eliminated because CA occupied the serial rehearsal mechanism and therefore participants were unable to rehearse in both the silence and sound conditions, thus equating performance in the two conditions. They argued that the addition of CA would not have removed the ISE unless participants had been rehearsing the words during the recognition and free recall tasks. Following these experiments, the view that the ISE is based on disruptions to serial rehearsal mechanisms returned to its position of dominance.

The Present Study

To test the role of serial rehearsal in the ISE more definitively, what is needed is a task that not only removes the need to maintain order information but also eliminates the chance that participants might rehearse the to-be-remembered items. This is the goal of this thesis. This series of experiments will employ a recognition memory task that does not require memory for order and further discourages, if not eliminates, rehearsal of to-be-remembered items by not informing participants of the need to remember the stimuli and engaging participants in an unrelated cover task during the study phase. If, based on this procedure, one can safely judge that the participants are not engaging rehearsal processes, and the ISE is still observed, then the results will falsify the O-OER model and its premise that a disruption of order information during serial rehearsal underlies the ISE.

If the interference that underlies the ISE does not impair serial rehearsal, then what process might it impair? To succeed in any memory task, regardless of the presentation method for to-be-remembered items, there are several key cognitive processes that must take place. The first is the activation of representations (e.g., activation of the perceptual, phonological and semantic representations of the to-be-remembered items). This activation is assumed to be automatic but may be compromised if the irrelevant sound interferes with successful phonological activation. Then, these activated representations must be encoded into working memory. This process requires attention, and can be described as the transformation of a set of unconscious activated features into a unified internal representation that is consciously available to the participant. After these representations are successfully encoded they must then be actively maintained (e.g., via rehearsal) for later retrieval. The serial verbal rehearsal strategy where one phonologically repeats the items (vocally or subvocally), keeping them alive for later retrieval, is the most common strategy for short term memory tasks with verbal material (e.g., Baddeley & Hitch, 1974). Imagine trying to remember a phone number. The simplest strategy would be to loop through the phone number repeatedly (obviously in the original order) out loud or internally until the number was dialled on a phone or written down on a piece of paper. The final process is the retrieval of that internal representation and its translation into a concrete external form (e.g., write down or verbally report the word list). Whether or not the task requires serial recall may be irrelevant if the rehearsal strategy itself is serial in nature. In this way, retrieval patterns may reproduce the rehearsal patterns.

Using these processes, it is possible to label the locus of the breakdown in memory performance for each of the models of the ISE. In light of the experimental evidence supporting the notion that irrelevant sounds disrupt serial rehearsal mechanisms, the breakdown occurs at serial rehearsal according to the most prominent model accounting for the ISE (i.e., O-OER; Jones, 1993). According to less prominent models of the ISE such as Broadbent's (1984) encoding disruption account or Cowan's (1995, 1999) embedded-processes model, the breakdown occurs during the attention-demanding encoding process where features of to-be-remembered items are initially transformed into a conscious internal representation in working memory. The feature model proposed by Nairne (1990) and extended by Neath (2000) suggests that the breakdown occurs at the initial activation of physical features of the item. Thus, according to the feature model, the mechanism for disruption is based on similarity between relevant and irrelevant items.

Summary of Experiments

Currently, it is unclear whether the ISE relies on disruption of order information, rehearsal, or encoding. Deciding whether or not verbal rehearsal underlies the ISE has been difficult because whenever participants know their memory for presented material will be tested, they may engage in serial rehearsal, even if the task itself does not require rehearsal (Beaman & Jones, 1997). In this series of experiments, I test whether the ISE can be observed in a surprise non-serial recognition paradigm where no rehearsal should take place and in which order information is irrelevant. Additionally, I test whether the

parameters of the ISE observed in a surprise non-serial recognition paradigm emulate the parameters observed in the accepted standard serial recall task.

Briefly, the task for Experiment 1 was as follows. Participants completed 200 lexical decision trials (press the “Z” key when a word appears; press the “M” key when a pseudo-word appears), during which pseudo-words and words were presented under conditions of silence or changing-state auditory tones. Participants were instructed to complete the lexical decision task as quickly and as accurately as possible; any sounds heard were to be ignored. Following the lexical decision task, participants were presented with a checklist of words, and were instructed to click on any words they remembered seeing during the lexical decision task in any order. Participants were not informed of this test prior to the lexical decision task. Thus, in this paradigm, it is safe to assume that participants were not rehearsing because they did not know their memory would be tested, and they were actively engaged in the lexical decision cover task. Additionally, the use of such a long list should have implicitly discouraged the use of any form of a serial rehearsal strategy (LeCompte, 1994; Salamé & Baddeley, 1990). To anticipate the results of Experiment 1, recognition memory was significantly impaired for words presented during irrelevant sound compared to words presented during silence. Thus, an ISE was nonetheless observed when participants were unlikely to be rehearsing. The results were unlikely to be due to interference from the phonological similarity of the relevant and irrelevant information given that auditory tones were presented as the irrelevant items and these were not phonologically similar to the visual words. Thus, the novel results in Experiment 1 lead me to suggest that, rather than disruption of rehearsal

processes as Beaman and Jones (1997) and the O-OER model (Jones, 1993) contend, or degradation of the phonological code as Nairne (1990) and Neath (2000) contend, the ISE relies on disruption of encoding of to-be-remembered items as suggested by Cowan (1995, 1999) and Broadbent (1984). Experiment 1 was used as the basis for the two subsequent experiments.

Experiment 1 used only changing-state irrelevant sounds (e.g., a sequence of randomly selected auditory tones) or silence. When a serial recall task is used, a robust ISE is observed when changing state sounds are used, but the ISE is diminished or even absent under conditions of steady-state sound (e.g., Jones et al., 1992). Little is known about the parameters of the ISE in non-serial recognition paradigms. To test whether the ISE observed in the surprise non-serial recognition task of Experiment 1 follows the same parameters as an ISE observed in a standard serial recall task, Experiment 2 tests the ISE under conditions of steady-state and changing-state irrelevant sounds both when a standard serial recall task is used, and when a surprise recognition memory test is used.

In Experiment 1, words from the lexical decision task were selected randomly for inclusion on the recognition checklist without regard for their serial position of presentation in the lexical decision task. This meant that no serial position curves could be calculated for the data in Experiment 1. However, it would be interesting to examine the shape of the serial position function for the surprise recognition memory task, and examine which positions, if any, show stronger or weaker effects of irrelevant sound. Therefore, in Experiment 2, words from the lexical decision task were sampled evenly from various serial positions such that a serial position curve could be calculated for the

noise and silence conditions. In paradigms where serial rehearsal is a likely strategy (e.g., serial recall), strong primacy effects and relatively weak recency effects were expected. In paradigms such as surprise non-serial recognition, where a serial strategy is unlikely to be used, a relatively flat serial position curve was expected. The primacy effect should be reduced due to the absence of a serial strategy, and the recency effect should be reduced because no items should be actively maintained in working memory. Examination of the interaction between irrelevant sound conditions and serial positions in both tasks has the potential to provide a clearer picture of the mechanisms underlying the ISE.

According to the *changing-state hypothesis* (Jones & Macken, 1993; 1995), the degree to which the irrelevant sound changes in terms of physical and acoustic properties predicts the amount of disruption in a serial recall task. The authors argue that seriation processes common in both irrelevant sound and to-be-remembered items underlie the ISE and that changing-state stimuli generate more seriation pointers that can interfere with rehearsal than do steady-state stimuli. Proponents of the O-OER model and the changing-state hypothesis (e.g., Beaman & Jones, 1997; Jones, 1993) would therefore predict a larger ISE with changing-state sounds than with steady-state sounds in the serial recall task, and no ISE in the surprise recognition memory task regardless of the nature of the sounds given that no serial rehearsal should be performed with this task. In contrast, I predicted that the ISE would be larger (i.e., greater memory disruption) with changing-state irrelevant sound than for steady-state irrelevant sound, in both the serial recall and surprise recognition memory tasks. If this pattern were to be observed, the greater

disruption by changing-state sound cannot be explained in terms of increased confluence of irrelevant with relevant seriation cues (i.e., disruption of order information) given that the surprise recognition memory task is unlikely to have resulted in serial rehearsal.

How could the changing-state effect be explained in a surprise recognition memory task that did not result in serial rehearsal? I contend that the changing-state effect could be explained in terms of habituation to the orienting response (OR; Sokolov, 1963). The OR can be described as an elicited response to novel stimuli and has been associated with a wide range of behavioural responses including head turns, parasympathetic activity, and deeper processing of the orienting stimulus. Indeed, Cowan's (1995) model suggests that the OR may operate as a mechanism for recruiting attentional resources away from a primary task (e.g., serial rehearsal). The OR framework proposes that repeated (i.e., steady-state) presentation of a given stimulus leads to the construction of a neural model (Sokolov, 1963). An orienting response is elicited when the presented stimulus fails to match the constructed neural model of expected stimuli (Escera, Yago, & Alho, 2001; Escera et al., 2003; Schröger, Giard, & Wolff, 2000; Schröger & Wolff, 1998). As the neural model is constructed, the perceived acoustical differences between the model and a given repeated stimulus decreases and leads to habituation of the OR. In this way, the OR framework can explain changing-state effects; repeated sounds are habituated very quickly whereas changing sounds are not habituated and may continue to recruit attentional resources away from a primary task, disrupting performance.

Thus in Experiment 2, an identical pattern of results (a larger ISE with changing-state irrelevant tones than with steady-state irrelevant tones) was predicted for the serial recall task whether one adopts the changing-state hypothesis or the OR framework. This is the pattern that already exists in the literature (e.g., Jones et al., 1992). The OR framework also allows one to explain how changing-state irrelevant stimuli could also disrupt performance more than steady-state stimuli in the incidental non-serial recognition paradigm. Such a pattern would help to discriminate between the two theoretical possibilities given that the absence of participant motivation to rehearse to-be-remembered items in the surprise recognition memory task removes the possible vehicle for order interference according to the changing-state view of Jones (1993). When rehearsal is absent, any cues to seriation generated by changing-state stimuli will have no mechanism for interference. Instead, changing-state effects could be considered through an OR framework given that the OR habituates for steady-state stimuli regardless of rehearsal.

Although, in Experiments 1 and 2, participants were actively engaged in a lexical decision task and should not have expected the impending memory test, some participants may have nonetheless rehearsed some to-be-remembered items, or even repeated them phonologically as they were encoded (e.g., Beaman & Jones, 1997). CA has been shown to eliminate the ISE in the standard serial recall task where serial rehearsal is the primary strategy (Baddeley, 1990a), and in LeCompte's non-surprise recognition memory tasks (Beaman & Jones, 1997). However, it remains an empirical question whether CA will abolish the ISE in a surprise non-serial recognition task where

participants are very unlikely to employ a serial rehearsal strategy. If CA abolishes the ISE in the surprise non-serial recognition task, then it will suggest that participants are nonetheless rehearsing to-be-remembered items or that phonological encoding of items is somehow critical to the ISE effect that is observed even under conditions of surprise recognition. However, if CA does not moderate the ISE, then a stronger argument can be made for performance disruption at encoding (e.g., Broadbent, 1983; Cowan, 1995) rather than the stage of rehearsal. Thus, Experiment 3 tests whether CA (repeated vocalization of the alphabetical series of letters A through G) eliminates the ISE in a surprise recognition memory test and compares this to the effects of CA on the ISE when using a serial recall task.

Experiment 1

Experiment 1 was designed to examine whether the engagement of serial rehearsal processes was necessary to observe the ISE. The dominant theory of the ISE argues that the ISE relies on a disruption of serial rehearsal processes, and that a task where participants do not use serial rehearsal should not show the ISE (Beaman & Jones, 1997; Jones, 1993). Given that participants who know they will need to remember items may choose to engage in serial rehearsal, even though the task would not require it, Experiment 1 examines the ISE under conditions where participants are *surprised* by a recognition memory test. If serial rehearsal processes do underlie the ISE, then to-be-remembered visual items presented with concurrent irrelevant changing-state auditory items should be equally likely to be reported as to-be-remembered visual items presented under a silent control condition (given that rehearsal is absent). However, if disruption of

serial rehearsal and order information is not required for the ISE, then an ISE may still be observed in the surprise recognition memory test.

Methods

Participants. Thirty-four undergraduate students (13 male) at Brock University participated in this experiment. Age ranged from 18 to 22 years with a mean of 19.15 years. All participants reported normal or corrected-to-normal visual acuity and none reported any auditory impairments. Participants were compensated with either a small honourarium (\$10) or research hours for a course.

Materials. All experimental stimuli were presented and responses collected using a Sony VAIO desktop computer running E-Prime v1.1 (Schneider, Eschman, & Zuccolotto, 2002). Visual stimuli were located centrally and presented in 18 point black Courier font on a white background using a 17 inch CRT monitor with a refresh rate of 75Hz. Stimuli were approximately 1cm high and 3cm to 5cm wide. At an unfixed viewing distance of approximately 50 cm, the visual angles were 1.2 degrees in height and 3.4 to 6.0 degrees in width.

The online MRC Psycholinguistic Database (http://www.psy.uwa.edu.au/mrc/database/uwa_mrc.htm; Kucera & Francis, 1967) was used to generate a pool of 720 monosyllabic words. All lexical stimuli were four to six letters in length, and words were emotionally neutral, and of moderate to high familiarity and concreteness. A second pool of 256 length-matched, phonotactically correct pseudo-words (e.g., GRONK) was also generated. Pseudo-words were designed such that all phonetic and morphemic rules of English were obeyed. None of the pseudo-words were homophones of real words (i.e.,

none had the phonology of a real world – e.g., “phox”). A total of 100 words and 100 pseudo-words were selected randomly from these pools and presented to each participant during the lexical decision phase of the experiment (25 additional words were selected randomly for presentation as foils during the recognition test phase). A given word was selected and displayed only once throughout the entire session, and selection was randomized for each participant.

Irrelevant auditory stimuli were 44 non-sinusoidal square waveforms, each 400ms in duration. Tones were presented at a rate of two tones per second ($ISI = 100ms$). Tones ranged in frequency (pitch) from 83Hz to 740Hz, equating to a span of three octaves in western music. Each tone was separated by one musical semitone which can be expressed as frequency change by a factor of 1.05946Hz. All auditory stimuli were ordered randomly, avoiding any musically meaningful or melodic combinations of tones. All tones were presented binaurally at an SPL of 70-75dB via noise isolating headphones.¹ All participants reported that the tone was presented at a clearly audible and comfortable volume. Because the timing of the presentation of visual items was based on the participant’s response to the previous trial (i.e., the timing between words was equal to 400 ms plus the participant’s response to the previous trial), and the timing of the tones was two per second, note that the tones were not presented synchronously with visual items. There is evidence that the ISE does not require synchronous presentation of relevant and irrelevant material (e.g., Salamé & Baddeley, 1982).

¹ This small variance in volume is tolerable given that the volume of the irrelevant sounds does not appear to play a role in its distraction potential (e.g., Salamé & Baddeley, 1987).

Design. A within-subjects design was used where all participants viewed words and pseudo-words under conditions of both noise (irrelevant changing-state tones were played through the headphones) and silence (no sounds were played through the headphones). The noise and silence trials were blocked with 100 trials per block and were counterbalanced for starting order across participants.

Procedure. Participants were tested individually and performed the tasks alone in a quiet room. Participants first performed the 200 lexical decision trials (one block of 100 trials with silence, and one block of 100 trials with changing-state noise). Within each block, 50 words and 50 pseudo-words were randomly selected and visually presented. Participants were told that they were participating in a study examining the impact of distracting material on task performance. Participants were not informed of the impending recognition memory checklist prior to starting the lexical decision task. They were told to simply concentrate on categorizing the visually presented items as words or pseudo-words as quickly and as accurately as possible (word = “press the Z key; pseudo-word = “press the M key”) while ignoring any auditory material they heard via the headphones. Each visual item remained on screen until a response was made by the participant. Following the participant’s response and a 400ms blank inter-trial interval, the next item was displayed. A short practice session of 10 lexical decision trials in silence was provided to familiarize participants with the task prior to performing any experimental trials. Immediately after completing all blocks of lexical decision trials, an instruction screen was displayed indicating to participants that they would be presented with a checklist of randomly selected words, some of which had been displayed during

the lexical decision task, and that they were to click on any words they remember seeing during the lexical decision portion of the experiment in any order. The checklist, comprised of 75 randomly selected and simultaneously displayed words (25 from the silent block; 25 from the irrelevant sound block; 25 new-at-test foils), was presented in five rows of 15 words each. When a participant clicked on a given word, it was highlighted with a yellow overlay (clicking the word a second time deselected the word and removed this highlight). No minimum or maximum number of responses was imposed, and no time limit was enforced. Clicking on a “next” button ended the checklist session. The checklist was presented only once at the end of the task. Participants were then debriefed and compensated.

Results

Lexical decision task.

Response time. For all response time (RT) measures, trials were included only if the item was identified correctly. Correct RTs were subjected to an outlier elimination procedure performed separately for each combination of participant, letter string (word/pseudo-word) and sound condition (silence or tones). Response times greater than three standard deviations from the mean were removed (fewer than 2% of all trials). A 2 (sound condition: silence versus tones) by 2 (item type: word versus pseudo-word) repeated measures analysis of variance (ANOVA) was employed to examine RTs to visual lexical decision items during silence or during presentation of irrelevant auditory stimuli. Sound condition and lexical item type were both within-participant factors. Results revealed a significant main effect of item type where RTs to words were 98 ms

faster than RTs to pseudo-words, $F(1, 33) = 29.40, p < .001$ (see Figure 2). A significant main effect for sound condition was also observed, whereby RTs to items presented concurrently with irrelevant changing-state tones were 27 ms faster overall than RTs to items presented during the silent control condition, $F(1, 33) = 11.59, p = .002$. The interaction between item type and sound condition was also significant, $F(1, 33) = 4.55, p = .040$. Follow-up paired-samples *t*-tests indicated that RTs to words presented in silence were not significantly different from RTs to words presented with irrelevant tones, $t(33) = 1.15, p = .26$. However, RTs to pseudo-words presented in silence were slower than RTs to pseudo-words presented with irrelevant tones, $t(33) = 4.37, p < .001$.

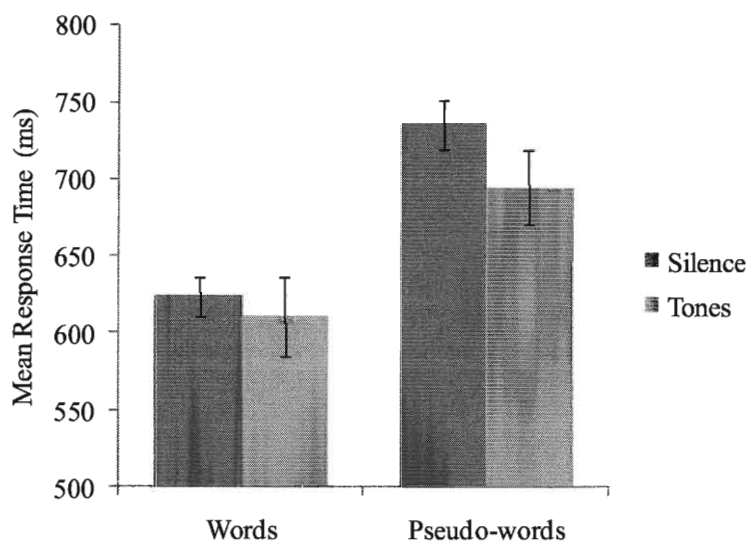


Figure 2. Mean Lexical Decision RTs in Experiment 1 as a function of lexical status and irrelevant sound condition. Error bars represent standard error for each mean.

Accuracy. The mean proportion of correct lexical decisions was submitted to a 2 (sound condition: silence versus irrelevant sound) by 2 (lexical item type: word versus pseudo-word) repeated measures ANOVA to investigate accuracy for visual lexical

decision items during presentation of irrelevant auditory stimuli. Neither the main effect for sound condition, $F(1, 33) = 1.71, p = .20$, nor the main effect for item type, $F(1, 33) = 2.10, p = .16$, was significant (see Figure 3 for means). However, the interaction between irrelevant sound condition and item type was significant, $F(1, 33) = 5.37, p = .027$.

Follow-up paired-samples t-tests indicated that accuracy scores were lower for words presented with irrelevant sound than words presented in silence, $t(33) = 3.12, p = .004$, but no significant differences were observed for pseudo-words, $t < 1$.

When examining the pattern of lexical decision RTs and accuracy, items presented with irrelevant sound showed shorter RTs and words also showed reduced accuracy. This pattern suggests the possibility of a speed-accuracy trade-off whereby the addition of irrelevant sound leads to careless performance in the lexical decision task, or the possibility of a bias to more quickly report items as pseudo-words (regardless of their identity) under conditions of irrelevant noise.

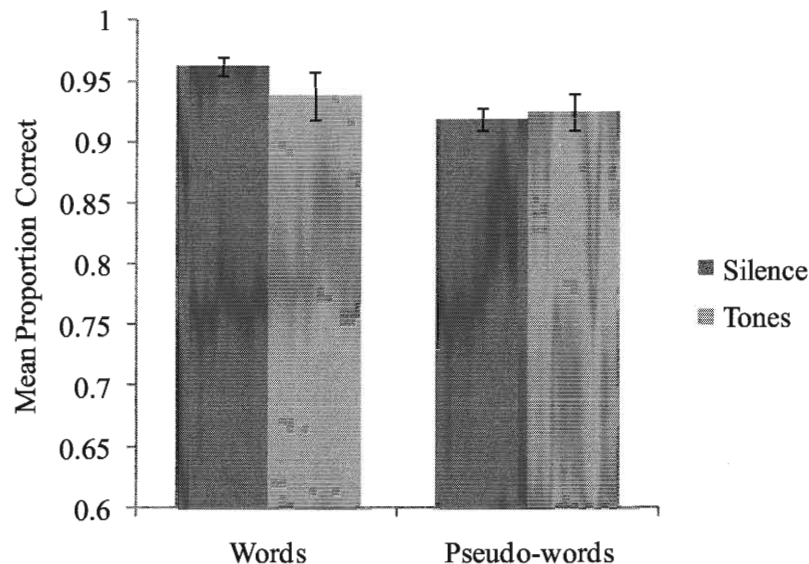


Figure 3. Mean Proportion Correct Lexical Decisions in Experiment 1 as a function of lexical status and irrelevant sound condition. Error bars represent standard error for each mean.

Recognition memory performance.

For each participant, memory sensitivity scores were calculated separately for words presented in silence and words presented with irrelevant tones (pseudo-words were not presented on the test list). Sensitivity scores were calculated by subtracting each participant's number of overall false alarms from their number of correct identifications on the checklist of words presented in each condition. This sensitivity score represents a participant's ability to differentiate old words (previously shown in the experiment) from new-at-test words.² Across all participants, the grand mean sensitivity score was .38 (SD

² It might be worth noting, that because all false alarm items were necessarily new words that were not presented previously under conditions of silence or noise, that the false alarms cannot be separated into silence and noise conditions, and therefore the same false alarm value was subtracted from both the silence and noise conditions. Thus, subtracting false alarms does not change the relative accuracy in the silence and noise conditions for a given participant—it simply reflects their overall ability more accurately.

= .18). A paired-samples *t*-test performed on the mean sensitivity scores as a function of sound condition (silence versus irrelevant changing-state sound) revealed a significant effect of sound condition, $t(33) = 3.36, p = .002$, where words presented with irrelevant tones during the lexical decision task were significantly less likely to be reported ($M = .35, SD = .182$) than words presented in silence ($M = .43, SD = .209$).

Discussion

The results of Experiment 1 are fairly straightforward. A significant ISE was observed in a surprise non-serial recognition memory task that does not encourage the use of a rehearsal strategy and does not require the maintenance of serial order information. The results mimic those of LeCompte (1994) where an ISE was observed in a task in which participants were permitted to report to-be-remembered items in any order. Indeed, the difference of 8% between changing-state and silence conditions approximated the 6% difference observed by Ellermeier and Zimmer (1997) when using the standard serial recall of digits task and by LeCompte (1994, Experiment 5C) when using a recognition procedure. However, the present task differs in one critical way. In the present task, participants were not told that they would need to remember the material and were engaged in an on-line lexical decision task during the presentation phase, which served to reduce the likelihood participants would suspect a memory test.

The lexical decision task also provided the additional benefit of calculating on-line performance costs associated with irrelevant sound. However, irrelevant sound led to shorter RTs overall as well as reduced accuracy for words, suggestive of a response bias or a speed-accuracy trade-off. Therefore, although there is clear evidence for an ISE

in the recognition memory scores, there is no clear evidence for on-line disruption of memory performance in the lexical decision scores.

Prominent models of the ISE such as the O-OER model (Jones, 1993) cannot readily explain the reduction in memory performance with irrelevant sound in this surprise recognition memory task. Recall that, according to the O-OER model, to-be-remembered items are arranged by a sequence of pointers or linkages in a unitary store. Auditory stimuli have direct access to this store and changing-state auditory stimuli automatically create seriation linkages. Visually presented stimuli are only entered into the unitary store through rehearsal. Through this process seriation linkages are generated for the visual items. Irrelevant sound disrupts memory performance through the perturbation of the seriation linkages formed between visual items by linkages formed between irrelevant auditory items. Thus, the O-OER model cannot explain the ISE in a task that does not require serial rehearsal.

However, in support of the O-OER model, Beaman and Jones (1997) argued that even though the nature of the recognition tasks used by LeCompte (1994) did not promote serial rehearsal, participants still knew they had to remember the items and so they may have nonetheless engaged a serial rehearsal strategy. Similarly, although the task used in Experiment 1 did not promote serial rehearsal and participants were not informed of the impending memory test, some participants may have still engaged in some form of rehearsal. If this is the case, then the O-OER model cannot be unequivocally ruled out. To more closely examine this possibility, Experiments 2 and 3 replicate the effect observed here while further examining the possible role of rehearsal in

the ISE. Experiment 2 examines whether changing-state, versus steady-state, sounds are more disruptive. Experiment 3 examines whether CA can eliminate the ISE observed in surprise recognition memory – a pattern that would be expected if rehearsal underlies the ISE results from the present experiment.

Experiment 2

As mentioned in the Introduction, a larger ISE has been reported with changing-state tones relative to steady-state tones (Jones & Macken, 1993). According to Jones and Macken (1993, 1995), irrelevant changing-state stimuli are markedly more disruptive to a primary task than irrelevant steady-state stimuli because of the increased confluence of irrelevant order cues with serial rehearsal processes. The authors argue that confusion in seriation processes common to both irrelevant stimuli and to-be-remembered items underlies the ISE. This is possible. However, it is also possible that the greater disruptive ability of irrelevant changing-state stimuli compared to irrelevant steady-state stimuli has nothing to do with serial rehearsal, and that changing-state stimuli may simply make it more difficult to encode the items from the primary task into working memory. For example, participants are less likely to habituate to changing-state stimuli than to steady-state stimuli, and the dynamic nature of changing-state stimuli may mean that they receive more attention (e.g., Cowan, 2001). In Experiment 1, I observed an ISE in a surprise recognition memory task using irrelevant changing-state stimuli. Here in Experiment 2, I examine whether the increased disruptive nature of changing-state stimuli (over steady-state stimuli) can be observed in a non-serial surprise recognition task as well as in a more typical serial recall task. Participants completed a serial recall

task that relied on serial rehearsal as well as the surprise recognition memory task from Experiment 1 where serial rehearsal was very likely to be absent. Both tasks were performed with changing-state irrelevant tones, steady-state irrelevant tones, and silence.

In the serial recall task where participants must rehearse both item and order information, I expected to replicate the results of Jones and Macken (1993) where a greater ISE was observed for changing- versus steady-state irrelevant sound (i.e. a greater difference between recall performance for changing-state versus silence compared to steady-state versus silence). If Jones and Macken are correct that changing-state sounds are more disruptive due to increased confluence of order cues during serial rehearsal, then a minimal difference in ISE size should be observed between steady- and changing-state conditions in the surprise non-serial recognition memory task, yet a robust difference in ISE size between steady- and changing-state conditions in the serial recall task. If, however, changing-state sound produces a markedly larger ISE than steady-state sound in the recognition task as a result of disruption at the level of encoding rather than serial rehearsal, then changing-state sound should produce a larger ISE in both the serial recall task and the surprise non-serial recognition task. If the pattern of results for the surprise recognition memory task matches the pattern of results for the serial recall task, then this would provide further evidence against disruption of rehearsal mechanisms during the ISE.

Methods

Participants. Forty-four Brock University undergraduate students (11 male) participated in this experiment. Ages ranged from 18 to 28 years with a mean of 20.20

years. All participants reported normal or corrected-to-normal visual acuity, none reported auditory impairment, and none had participated in Experiment 1. All participants reported learning English as their first language. Participants were compensated with either a small honourarium (\$10) or research hours for a course.

Materials. All words and pseudo-words were identical to Experiment 1 with the exception that the word set was extended to 135 words and 108 pseudo-words for the recognition memory task. Additionally, 288 (18 for the practice trials; 270 for the experimental trials) words were selected from the pool and used for the serial recall task. Each word was used only once in the experiment, either in the recognition task or the recall task, but not both. Words were assigned randomly to each task separately for each participant.

The changing-state stimuli and the presentation conditions were the same as the tone presentations in Experiment 1. The steady-state distractors consisted of the repeated presentation of a single auditory stimulus selected randomly on each trial from the same set of tones used for the changing-state stimuli. This single repeated tone was presented for the same duration at the same rate, and under the same conditions as the changing-state tones (i.e., the only difference between the changing-state condition and the steady-state condition was whether the pitch of the tone changed from tone to tone, or stayed constant for all tones).

Design. Experiment 2 employed a within-subjects experimental design with two factors: 1) irrelevant sound condition (silence, steady-state, and changing-state tones), and 2) task (serial recall versus surprise recognition). Task was blocked, and to maintain

the element of surprise for the surprise recognition memory task, all participants completed the recognition memory task prior to receiving instructions for the serial recall task.

For the surprise recognition task, all participants performed 216 lexical decision trials (108 words, 108 pseudo-words). Items were divided equally into three 72-trial blocks: silence, steady-state tones, and changing-state tones. Each block contained 36 words and 36 pseudo-words randomly selected and displayed. Each participant completed all three blocks in an order determined in advance by permutation (ABC; BCA; CAB; CBA; ACB; BAC) such that irrelevant sound condition order was counterbalanced every six participants. The surprise recognition checklist was composed of 27 words from each condition block as well as 27 words that were new-at-test (foils), for a total of 108 words. The recognition checklist words were presented in random order all at the same time in six columns of 18 words. To analyze serial position effects in the paradigm, three words were randomly selected for test on the surprise recognition test from each subset of eight items (four words; four pseudo-words) in each block of the lexical decision task. Given that each block was composed of 36 words and 36 pseudo-words, nine 8-item subsets were generated. From each 8-item subset, three words were randomly selected for test on the checklist. Using this approach it was possible to examine where in the presentation list items were most susceptible to disruption by irrelevant sounds. It also permitted a rough comparison of serial position curves between the surprise recognition task and the standard serial recall task.

The serial recall task used words drawn from the same set as the recognition task (although each word appeared only once on one of the two tasks for any given participant). On each trial nine new words were randomly selected and displayed in the centre of the screen one at a time in 18 point font at a rate of one per second. Participants were told to remember the nine items on each trial and to recall the words in the same order as presented by writing each word down on a piece of paper. A total of 30 sets were presented over three blocks (10 in silence, 10 with concurrent irrelevant steady-state tones, and 10 with concurrent irrelevant changing-state tones). Each participant completed all three blocks in an order determined in advance by permutation (ABC; BCA; CAB; CBA; ACB; BAC) such that irrelevant sound condition order was counterbalanced every six participants.

Procedure. Participants were tested individually and performed the tasks alone in a quiet room. All participants completed the surprise recognition task first and were not forewarned of the impending memory test. As in Experiment 1, they were told that they were completing a task that assesses categorization speed and accuracy under various forms of distraction, and were told to ignore any auditory stimuli they heard. Speed and accuracy were stressed. Thus, it is unlikely that participants were rehearsing items for later retrieval. Participants first performed ten lexical decision practice trials in silence to familiarize themselves with the task. Participants performed all lexical decision trials as they did in Experiment 1. Written instructions appeared on the screen prior to each block to inform them of the change in auditory stimuli. After completing all three blocks (silence, steady-state, changing-state irrelevant sound), participants then

completed the recognition checklist as they did in Experiment 1. Memory was tested only once.

Following the surprise recognition task, participants completed the serial recall task. Participants were informed that they would be presented with nine new words on each trial in random order and were told to remember the words during their presentation and for 10 seconds after the last word (until the word “recall” appeared). Participants were told to write down the words in the same order as presented. They were informed that 10 sets would be completed in silence, 10 with concurrent steady-state tones, and 10 with changing-state tones but that they should simply ignore the sounds. Participants were informed that these irrelevant sounds would be the same as those from the surprise recognition task. Participants were also provided with two practice sets in silence before beginning the experimental trials. After completion of the recall task participants were debriefed and compensated.

Results

Lexical decision task.

Response time. For all RT measures, trials were included only if the item was identified correctly. Correct RTs were subjected to an outlier elimination procedure performed separately for each combination of participant, letter string (word/pseudo-word) and sound condition (silence or steady-state or changing-state). Response times greater than three standard deviations from the mean were removed (fewer than 2% of all trials). A 3 (Sound Condition: silence versus steady-state versus changing-state) by 2 (item type: word versus pseudo-word) repeated measures ANOVA was employed to

examine RTs to visual lexical decision items during silence or during presentation of irrelevant changing- or steady-state auditory stimuli. Sound condition and lexical item type were both within-participant factors. Results revealed a significant main effect of item type where RTs to words were 93 ms faster than RTs to pseudo-words, $F(1, 43) = 37.63, p < .001$ (see Figure 4). A significant main effect for sound condition was also observed, $F(2, 86) = 3.42, p = .037$. Follow-up planned paired-samples t-tests indicated that the only statistically significant difference was between the changing-state sound and silence conditions, $t(43) = 2.67, p = .011$ where lexical decision RTs were longer on silence blocks than on changing-state blocks. The difference between changing-state and steady-state sound conditions, $t(43) = 1.42, p = .163$, and the difference between steady-state sound and silence conditions, $t(43) = 1.21, p = .234$, were not significant. The interaction between item type and sound condition was also significant, $F(2, 86) = 3.13, p = .049$. Follow-up one-way ANOVAs, performed separately on RTs to words and RTs to pseudo-words, showed that RTs did not differ across sound conditions for words, $F(2, 86) = 1.09, p = .341$. However, RTs differed across sound conditions for pseudo-words, $F(2, 86) = 5.09, p = .008$. Planned paired-samples t-tests indicated that RTs differed only between the changing-state sound and silence conditions, $t(43) = 3.16, p = .003$ (all other $ps > .10$).

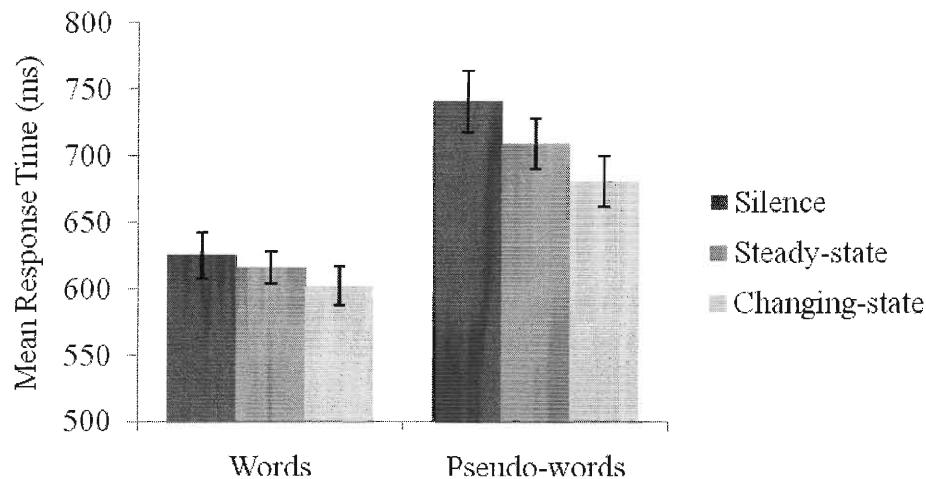


Figure 4. Mean Lexical Decision RTs in Experiment 2 as a function of lexical status and irrelevant sound condition. Error bars represent standard error for each mean.

Accuracy. The mean proportion of correct lexical decisions was submitted to a 3 (sound condition: silence versus steady-state versus changing-state) by 2 (lexical item type: word versus pseudo-word) repeated measures ANOVA to investigate accuracy for visual lexical decision items during presentation of irrelevant auditory stimuli. Results indicated a main effect for item type whereby accuracy for pseudo-words was 6% lower than accuracy for words, $F(1, 43) = 7.41, p = .009$. Neither the main effect for sound condition, $F(2, 86) = 2.02, p = .138$, nor the interaction between item type and sound condition, $F(2, 86) < 1, p = .811$, was significant (see Figure 5 for means).

Overall, the pattern of lexical decision RTs and accuracy suggests that, irrelevant sound leads to faster lexical decisions to pseudo-words without any cost to accuracy.

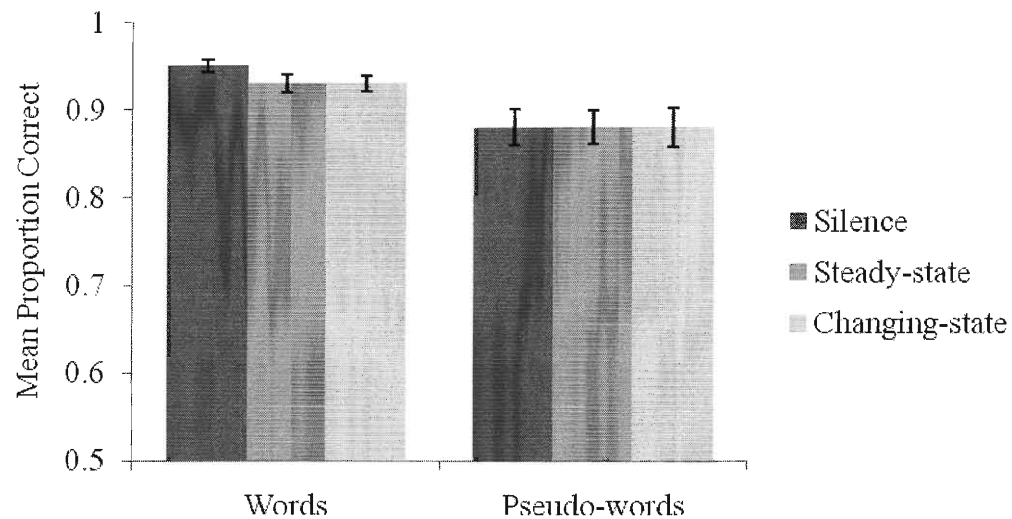


Figure 5. Mean Proportion Correct Lexical Decisions in Experiment 2 as a function of lexical status and irrelevant sound condition. Error bars represent the standard error for each mean.

Memory performance.

Surprise non-serial recognition. For each participant, memory sensitivity scores were calculated separately for words presented in silence, words presented with irrelevant steady-state tones, and words presented with irrelevant changing-state tones (pseudo-words were not presented on the test list). Sensitivity scores were calculated by subtracting each participant's number of overall false alarms from their number of correct identifications on the checklist of words presented in each condition. This sensitivity score represents a participant's ability to differentiate old words (previously shown in the experiment) from new-at-test words. Across all participants, the grand mean sensitivity score was .35 ($SD = .16$).

Mean sensitivity scores were submitted to a 3 (sound condition: silence versus steady-state versus changing-state irrelevant sound) by 9 (serial position) repeated

measures ANOVA. A main effect for sound condition was observed, $F(2, 86) = 4.26, p = .017$ (see Figure 6a). Follow-up paired-samples t-tests indicated that, compared with the silence condition, sensitivity scores were lower in both steady-state irrelevant sound, $t(43) = 2.89, p = .006$, and changing-state irrelevant sound conditions, $t(43) = 2.24, p = .030$, but that the two irrelevant sound conditions did not differ from each other, $t(43) < 1, p = .891$. A main effect of serial position was also observed, $F(8, 344) = 2.60, p = .009$ (see Figure 6b) where recognition accuracy increased with serial position. The interaction between sound condition and serial position was not significant, $F(16, 688) < 1, p = .773$, suggesting that the ISE is not confined to specific positions.

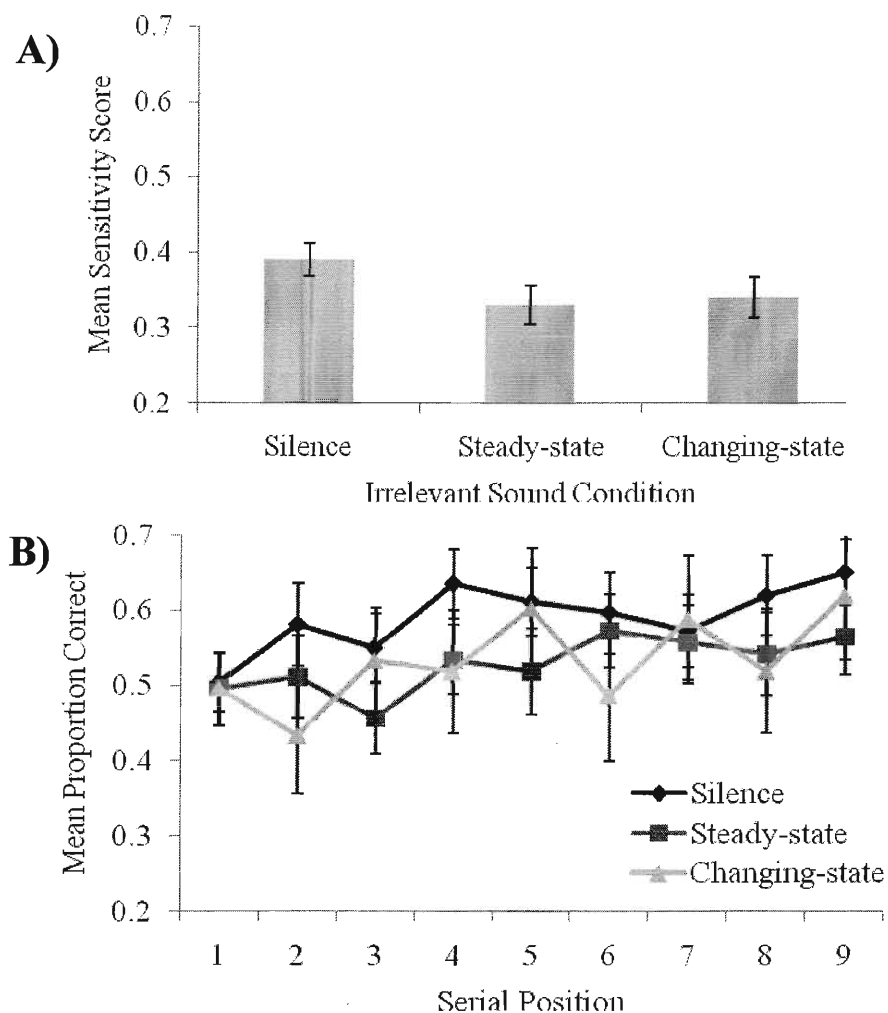


Figure 6. Memory performance on the surprise recognition memory test based on words presented in Lexical Decision task in Experiment 2. A) Mean sensitivity scores (hits-false alarms) for words as a function of sound condition. B) Mean probability of recognition as a function of sound condition and serial position in the Lexical Decision task.

Serial recall (conservative scoring method). For each participant, serial recall scores were calculated separately for words presented in silence and words presented with steady- and changing-state irrelevant tones. For each trial, participants were given a score out of nine (nine words were presented per trial). A “point” was awarded for each word correctly recalled in the correct position. In this way, a strict serial scoring rule was applied. Recall proportions were averaged across the 10 trials within each sound condition. Across all participants and conditions, the grand mean proportion of correct recalls was .33 (SD = .11). Mean recall scores were submitted to a 3 (sound condition: silence versus steady-state versus changing-state irrelevant sound) by 9 (serial position) repeated measures ANOVA. A main effect of serial position was observed whereby items presented at the beginning or the end of the 9-item set were more likely to be recalled, $F(8, 344) = 64.97, p < .001$ (see Figure 9 for means). The main effect of sound condition, $F(2, 86) = 1.00, p = .371$, was not significant. Planned-comparison t-tests on the mean proportion of words recalled across sound conditions, after collapsing serial position, confirmed this pattern, all $ps > .20$ (see Figure 7 for means). However, the interaction between sound condition and serial position was significant, $F(16, 688) = 2.28, p = .003$. Follow-up one-way ANOVAs calculated separately at each position revealed only one significant difference at position 8, $F(2, 86) = 3.62, p = .03$. A follow-up paired-samples t-test revealed that only the contrast between the changing-state and the silent condition was significant, $t(43) = 2.59, p = .013$. The one-way ANOVAs performed at position 6, $F(2, 86) = 2.89, p = .061$ approached significance. All other comparisons were not statistically significant, all $ps > .08$. Separate one-way ANOVAs

were also performed for each sound condition. Analysis revealed that the effect of position was significant for each irrelevant sound condition (silent, $F(8, 344) = 34.89, p < .001$; steady-state, $F(8, 344) = 36.36, p < .001$; and changing-state, $F(8, 344) = 46.88, p < .001$).

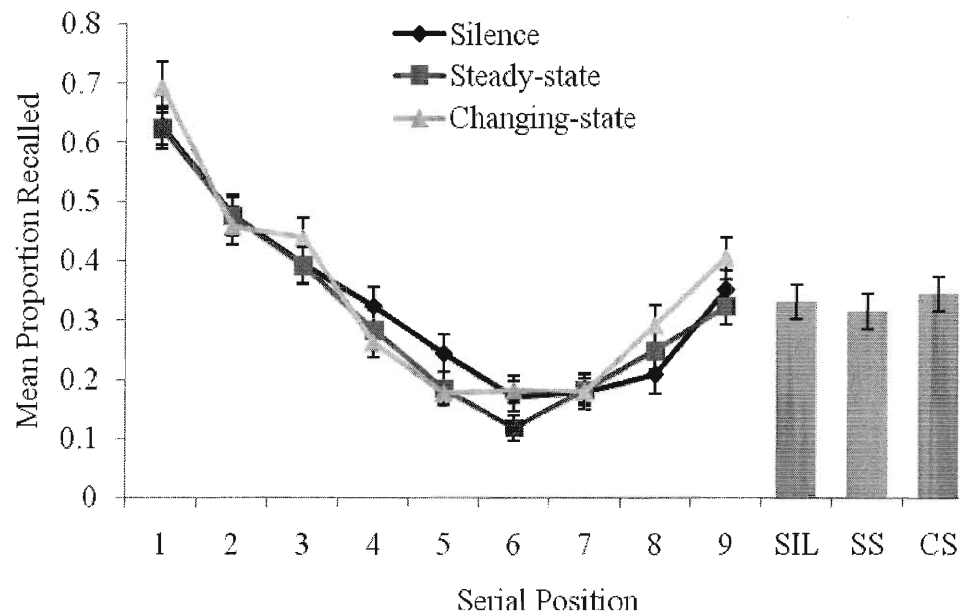


Figure 7. Memory performance in the serial recall task of Experiment 2. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition and serial position. Columns represent mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL), steady-state irrelevant sound (SS), and changing-state irrelevant sound (CS) averaged across serial positions. Error bars represent standard error for each mean.

Serial recall (scoring without order constraints). The data from the standard serial recall task were also examined without regard for serial order performance. For each trial, participants were given a score out of nine (nine words were presented per

trial). Using this liberal method, no restriction for order was imposed on the recall scores. A “point” was awarded for each word correctly recalled regardless of the order in which it was recalled. For each participant, recall scores were calculated separately for words presented in silence and words presented with steady- and changing-state irrelevant tones. Recall proportions were averaged across the 10 trials within each sound condition. Across all participants and conditions, the grand mean proportion of correct recalls was .41 (SD = .11). Mean recall scores were submitted to a 3 (sound condition: silence versus steady-state versus changing-state irrelevant sound) by 9 (serial position) repeated measures ANOVA. A main effect of position was observed whereby items presented at the beginning or the end of the 9-item set were more likely to be recalled, $F(8, 344) = 30.58, p < .001$ (see Figure 8 for means). The main effect of sound, $F(2, 86) = 2.10, p = .129$, was not significant, nor was the interaction between sound condition and serial position, $F(16, 688) < 1, p = .465$. Planned-comparison t-tests on the mean proportion of words recalled across sound conditions revealed a pattern similar to the results of the surprise non-serial recognition task. Compared with the silence condition, a trend was observed for a lower proportion of correctly recalled words in both the steady-state irrelevant sound, $t(43) = 1.69, p = .097$, and changing-state irrelevant sound conditions, $t(43) = 1.81, p = .078$, but the two irrelevant sound conditions did not differ from each other, $t(43) < 1, p = .661$.

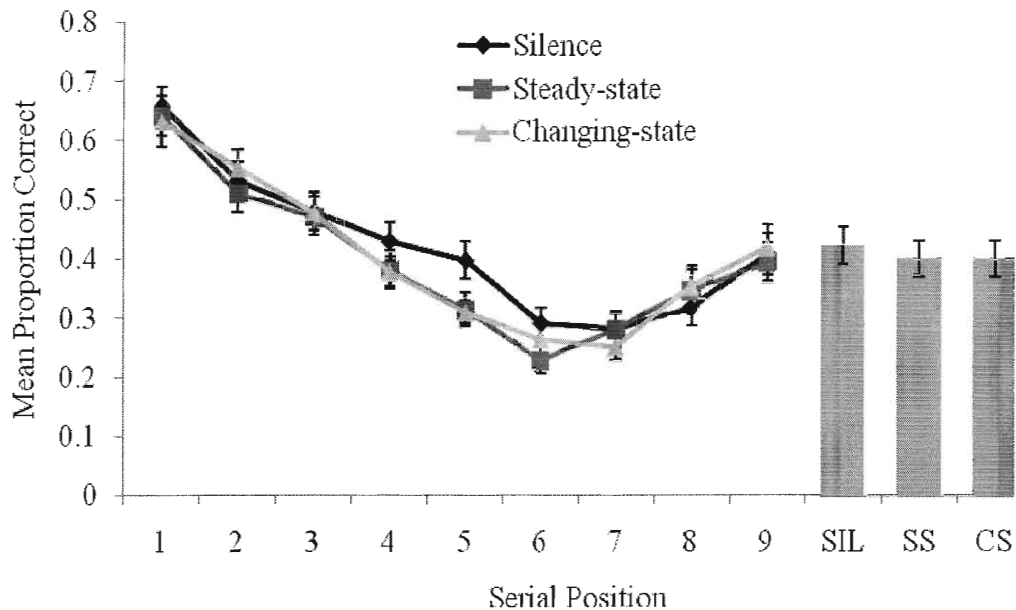


Figure 8. Memory performance in the serial recall task in Experiment 2 scored without regard for recall order. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition and serial position. Columns represent overall mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL), steady-state irrelevant sound (SS), and changing-state irrelevant sound (CS), collapsed across serial position. Error bars represent standard error for each mean.

Discussion

In general, the results from the surprise non-serial recognition task of Experiment 2 replicate the results of Experiment 1. A significant ISE was again observed in a surprise recognition memory task that did not encourage the use of a rehearsal strategy and did not require the maintenance of serial order information. In this task, participants were not told that they would need to remember the material and were additionally engaged in an on-line lexical decision task during the presentation phase, which served to reduce the likelihood that participants would suspect the memory test. Compared with

the results from the surprise non-serial recognition task in Experiment 1 which revealed a difference of 8% between sensitivity scores under the changing-state versus silent conditions, the surprise recognition results of Experiment 2 showed a similar, but slightly smaller, difference of 6% between the changing-state and silence conditions.

The lexical decision task also provided the benefit of calculating on-line performance costs associated with irrelevant sound. As in Experiment 1, in Experiment 2, the presence of irrelevant sound led to faster RTs, although this time without any change in response accuracy. Therefore, irrelevant sound may speed up participants such that they allocate less time for elaborative encoding of each item.

Surprise non-serial recognition & changing- versus steady-state. The presence of a significant ISE in the surprise recognition memory task of Experiment 2 provides evidence that the ISE is not driven by disruptions to rehearsal or memory for serial order. However, finding an equally large ISE with both changing-state and steady-state conditions suggest that any form of irrelevant sound, regardless whether it is qualitatively changing-state or steady-state, can disrupt memory performance in a surprise non-serial recognition task. As expected, plots of serial position curves from the surprise non-serial recognition task show a relatively flat curve lacking clear primacy or recency effects. Although there was a slight trend towards better memory for items falling near the end of each presentation phase, the overall curve is noticeably flatter than the curves plotted for the serial recall task. This flattened curve suggests that participants were not actively rehearsing to-be-remembered items in this task, and provides further evidence against the notion that irrelevant sound disrupts rehearsal processes.

In contrast to the predictions made by the O-OER model and the changing-state hypothesis, a significant ISE was observed in the surprise non-serial recognition task. Given that rehearsal and order information were presumably absent in the surprise recognition memory task, the changing-state hypothesis (Jones & Macken, 1993) as well as the O-OER model (Jones, 1993), which rely on disruption of these processes, fail to account for the presence of an ISE in the surprise recognition task. Recall that, according to the O-OER model, visually presented to-be-remembered items are arranged by a series of pointers or linkages in a unitary store. Irrelevant auditory stimuli automatically create additional seriation linkages. Irrelevant sound disrupts memory performance through the perturbation of the seriation linkages formed between visual items by linkages formed between irrelevant auditory items. Changing-state stimuli, compared with steady-state stimuli, generate more linkages and thus should disrupt memory performance in any primary task where serial rehearsal is the dominant strategy. Thus, the notion that the number of changes present in the irrelevant sound predicts memory impairment is weakened. A possible counter explanation is that the representation of each to-be-remembered item is perturbed at the moment it is presented. This pattern cannot be explained in terms of disruptions to rehearsal or order information.

The O-OER model, changing-state hypothesis, and the OR-based fail to account for the surprise recognition data in Experiment 2. In contrast with the OR-based prediction, both changing-state *and* steady-state irrelevant sound equally impaired surprise non-serial recognition memory performance. According to this framework, changing-state irrelevant sound should reach habituation more slowly than steady-state

sound and should thus be more disruptive to memory performance. However, because steady-state and changing-state irrelevant sound disrupted performance equally, a different explanation is required.

It is tempting to suggest that a stronger manipulation of steady-state versus changing-state irrelevant sound would help to generate the anticipated pattern of results. One could argue that the use of a single repeated tone still possesses changing-state properties. For example, the onset and offset of each tone, although regular, could be interpreted as a changing property. A more appropriate source of steady-state stimuli could be white or pink noise which is a more continuous sound source and does not contain any abrupt “change”. Thus, a comparison between changing-state irrelevant tones and steady-state white/pink noise may provide the pattern predicted by the changing-state hypothesis: changing-state sound is disruptive compared to steady-state sound and a silent control condition. However, earlier research contrasting serial digit recall performance in silence versus white noise bursts (which also have an “on then off” pattern) yielded null ISE results (Jones & Macken, 1993; Salamé & Baddeley, 1982). Interestingly, both Salamé and Baddeley’s results and those of Jones and Macken (1993) showed the same pattern: white noise bursts (steady-state) generated numerically more serial recall errors than silence but fewer errors than irrelevant words (changing-state). This non-significant pattern is noteworthy in light of the fact that a small sample was used in both studies: only 18 participants were examined by Salamé and Baddeley (1982) and only 24 by Jones and Macken (1993). To test the notion that the failure to find differences resulted from lack of power, it may be beneficial for future studies to examine

irrelevant white/pink noise as the steady-state irrelevant sound source using a larger sample. Indeed, using 50 participants, LeCompte (1994, Experiment 1) found the predicted pattern of results in a serial letter recall task using white noise: Irrelevant speech (changing-state) was most disruptive to serial recall compared to both white noise bursts (steady-state) and silence. Critically, white noise bursts were still disruptive to serial recall relative to the silent control. Thus, even steady-state stimuli repeating in an on-off pattern at a regular interval may lead to a modest ISE, suggesting continuous white/pink noise as a more appropriate steady-state condition. Anecdotally, some participants reported the steady-state sound condition to be more “abrasive” or “annoying” than the changing-state sound condition. This heightened “annoyance” may have lead to greater interference from the steady-state sound.

The study that is cited routinely as evidence that an ISE can be observed with changing-state tones but not steady-state tones is Experiment 1 of Jones and Macken (1993). However, closer examination of their results suggests that this conclusion is somewhat suspect. Interestingly, Jones and Macken (1993; Experiment 1) identified serial recall performance differences between only the changing-state sound condition and the silent control and no significant difference between steady-state and either of the other conditions. Because recall performance in the steady-state irrelevant sound condition did not differ from either the silent or changing-state sound condition, Jones and Macken concluded that only changing-state sound is disruptive to serial recall performance. Therefore, the present study replicates the serial recall pattern observed by Jones and Macken (1993) in finding no significant difference in serial recall performance

for steady-state versus changing-state. However, the present results show a significant difference in surprise non-serial recognition for steady-state versus silence, and this difference was not significant in Jones and Macken's (1993) experiment.

Serial recall. Where the O-OER model and the changing-state hypothesis should succeed is in predicting the results of standard serial recall tasks where rehearsal and maintenance of order information are both integral to the task. Both of these theories predict serial recall impairments associated with irrelevant sound; both theories additionally predict that only changing-state irrelevant sound should be disruptive compared with steady-state irrelevant sound (due to increased confluence of irrelevant with relevant seriation cues). The results from the serial recall task of Experiment 2, using the conservative scoring method, do not support this view. Unlike the results from the surprise non-serial recognition task, irrelevant sound, either changing-state or steady-state, did not impair serial recall performance compared to a silent control. Critically, there was clearly no difference in memory performance between changing-state and steady-state irrelevant sound conditions.

However, when these same recall data were rescored without regard to order (i.e., a "point" was awarded to a participant if the correct word was recalled even if it was not in the correct serial position), a trend towards an ISE was observed.³ These results mimicked the pattern observed in the surprise non-serial recognition task whereby changing- and steady-state irrelevant sounds were equally disruptive to memory

³ Note that the instructions to the participants were "write down the words in the same order as presented". Thus the liberal scoring of the serial recall task is not equivalent to a non-serial recall task. If the experimenter had instructed participants to report the items in any order, it is possible that the observed trend may have reached traditional levels of statistical significance.

performance relative to a silent control. Although one should always exercise caution when interpreting statistical trends, this pattern suggests that the preservation of order information may not be the only locus of disruption in the ISE in serial recall tasks – a conclusion also supported by the finding of an ISE in the surprise recognition task.

Jones and Macken (1993) observed a significant ISE with a serial recall task and changing-state irrelevant tones versus silence. Although I expected to replicate this effect in the serial recall task used here, no significant ISE was observed for changing-state tones versus silence. Jones and Macken (1993, Exp. 1) used a serial recall paradigm wherein participants were asked to report seven letters (F K L M O R Y) in the same order as presented under conditions of silence, steady-state and changing-state irrelevant sound. The experimental procedure used here differs from that of Jones and Macken (1993) in several key ways. The most obvious difference is that Jones and Macken used a finite set of to-be-remembered letters whereas, in the present experiment, a virtually unlimited pool of to-be-remembered words was used such that no item was repeated. Thus, in addition to maintaining order information, participants in the present experiment were also required to remember the content of each stimulus. Because each of the seven letters in the set was presented once on each trial, participants in Jones and Macken's experiment knew what letters would be presented on each trial, and simply had to remember the order in which items were presented. The absence of a significant ISE in the changing-state versus silence conditions of the present experiment raises the interesting possibility that the ISE may only be observed in a serial recall task when the

memory set includes the same set of to-be-remembered items on each trial. Experiment 3 will provide another opportunity to examine this possibility.

It is also possible that the greater task difficulty in the present experiment lead to floor effects, which would reduce the possible range of scores. Compared to previous experiments conducted in our lab that more closely paralleled the task and results found by Jones and Macken (using only letters as to-be-remembered material), recall probabilities are approximately 10% lower. Thus, the additional demands of remembering item information, in addition to order information, may have contributed to the null findings.

Another possibility for the discrepancy between the present results and those of Jones and Macken (1993, Experiment 1) is that participants in the present experiment may have already habituated to the irrelevant changing-state auditory stimuli used in the serial recall task. Prior to completing the serial recall task, all participants completed the surprise non-serial recognition task which used the same irrelevant sounds. According the Orienting Response (OR; Sokolov, 1963) framework, a neural model is built to represent the auditory stimulation. Whenever the presented stimulus fails to match the constructed neural model of expected stimuli, an orienting response is elicited and attention is diverted towards the novel stimulus and away from the primary task. According to this framework, steady-state stimulation was expected to habituate very quickly whereas changing-state stimulation was not expected to habituate, thus producing differential memory performance in each condition. However, in the present experiment, serial recall was not significantly impaired by steady-state or changing-state irrelevant

sound. What may explain this pattern is habituation to all irrelevant stimuli during the surprise non-serial recognition task such that presentation of both steady-state and changing-state stimuli were perceived as familiar and representative of the neural model constructed during the first task. Given that no novel stimuli would be detected, an orienting response would not have been generated and thus no diversion of attention away from the primary task. Had participants completed *only* the serial recall task as in Jones and Macken's (1993) experiment, the pattern of results may have been different.

Taken together, the results of the surprise recognition task in Experiment 2 replicate Experiment 1, showing that neither rehearsal nor maintenance of order information is necessary to observe the ISE. However, results from the steady-state versus changing-state manipulation did not support the predictions of the O-OER model (Jones, 1993), the changing-state hypothesis (Jones & Macken, 1993), or OR-based predictions. Surprise non-serial recognition memory was equally impaired by both changing-state and steady-state irrelevant sound. Using a serial recall paradigm in which both order information and item content were integral to the task failed to show the anticipated pattern of results in that serial recall of words was not impaired by either type of irrelevant sound. However, when serial recall performance was re-quantified without regard for serial order, a pattern of results numerically similar to that of the surprise non-serial recognition task emerged. The results from the experiment suggest that disruptions to the maintenance of order information cannot fully explain the ISE in a serial recall task, and that future studies should investigate further the impact of steady-state versus changing-state irrelevant sounds with a variety of tasks, using larger sample sizes.

Experiment 3

LeCompte (1994) first revealed a significant challenge to the changing-state hypothesis after finding the ISE with free recall, paired-associates, and recognition tasks. However, Beaman and Jones (1997) argued that even though the nature of the tasks used by LeCompte (1994) did not require or promote serial rehearsal, participants still knew they had to remember the items and so they may have serially rehearsed to-be-remembered items even when it was unnecessary to do so to succeed in the task. If participants really were performing serial rehearsal then LeCompte's results did not actually challenge serial rehearsal models of the ISE, as according to the changing-state hypothesis, these rehearsed items were consequently susceptible to disruption by irrelevant changing-state stimuli. Beaman and Jones (1997) provided support for the assumption that LeCompte's participants were rehearsing the items by demonstrating that CA eliminated the ISE even in these non-serial tasks. CA is thought to suppress the process of serial rehearsal by occupying the mechanism of phonological articulation of to-be-remembered items such that irrelevant sound cannot additionally interfere. Thus, if the ISE relies on serial rehearsal in a given task, it should be eliminated under conditions of CA.

Following this logic, the purpose of Experiment 3 was to determine whether CA eliminates the effect of irrelevant sound in a surprise non-serial recognition memory task that I contend does not rely on rehearsal or serial information. If the ISE reflects a disruption of rehearsal processes (Beaman & Jones, 1997), even in a surprise recognition task, then adding CA to the task should eliminate differences between silent and

irrelevant sound conditions, as it does with serial recall tasks. However, if CA has no impact on the magnitude of the ISE in the surprise recognition memory task where serial rehearsal is unlikely to be employed, then this would provide further evidence against the rehearsal-based O-OER account of the ISE.

Method

Participants. Seventy-three undergraduate students (16 male) enrolled at Brock University were recruited for participation. Ages ranged from 18 to 26 years with a mean of 19.92 years. As in previous experiments, participants had normal or corrected-to-normal vision, reported no hearing impairments, and did not participate in previous ISE experiments from the lab. Participants were compensated with a small honourarium (\$10) or research hours for a course.

Materials. For the recognition memory task, all experimental stimuli (auditory tones and visual words), presentation conditions and instructions were identical to those used in Experiment 1. However, half of the participants were also required to vocalize the alphabetical sequence of letters A through G (Beaman & Jones, 1997) during the lexical decision task. For the serial recall task, the auditory tones, visual words, presentation conditions and instructions were identical to those used in Experiment 2 with the exception that there was no steady-state condition and half of the participants were also required to vocalize the alphabetical sequence of letters A through G (Beaman & Jones, 1997) during the presentation of the words and during the subsequent 10 second rehearsal interval.

Design. The experiment used a mixed-model experimental design with task (serial recall versus recognition) and irrelevant sound condition (changing-state tones versus silence) being within-participant factors, and CA (present/absent) being a between-participants factor. Task and irrelevant sound condition were blocked, and to maintain the element of surprise for the surprise recognition memory task, all participants completed the recognition memory task prior to being informed of the serial recall task.

During the surprise recognition task, all participants performed 216 lexical decision trials (108 words, 108 pseudo-words). Items were divided equally into two 108-trial blocks: silence and changing-state tones. Each block was divided equally into 54 words and 54 pseudo-words randomly selected and displayed. Each participant completed both blocks, with start order counter-balanced across participants. The surprise recognition checklist was composed of 36 words from the silence condition, 36 words from the changing-state tones condition, as well as 36 words that were new-at-test (foils). To analyze serial position effects, four words were randomly selected for test on the surprise recognition test from each subset of 12 items (six words; six pseudo-words) in each block. Each block was composed of 54 words and 54 pseudo-words, and nine 12-item subsets (6 words and 6 pseudo-words) were generated. Four words were randomly selected from each subset such that 36 words were selected from each condition for display on the recognition checklist (9 subsets x 4 words per subset = 36 words per condition). In this way it was possible to examine where in the presentation list items were most susceptible to disruption by irrelevant sounds. It also permitted a rough

comparison of serial position curves between the surprise recognition task and the standard serial recall task.

As in Experiment 2, during the serial recall task participants were told to rehearse and recall each set of nine words in the same order as presented. A total of 30 sets were presented (15 in silence, 15 with concurrent irrelevant changing-state tones). The irrelevant sound condition was blocked and counterbalanced with each participant receiving the same block order they received in the recognition task.

Procedure. Participants were tested individually and performed the tasks alone in a quiet room. Unlike Experiments 1 and 2, participants had the cubicle door open throughout the experiment so that the experimenter could listen and ensure that participants in the CA condition were indeed vocalizing the letters during the lexical decision task and study/retention phases of the serial recall task. All participants completed the surprise recognition task first and were not forewarned of the impending memory test. As in previous experiments, they were informed that they would be completing a task that assesses categorization speed and accuracy under various forms of distraction, and were told to ignore any auditory stimuli. Speed and accuracy in the lexical decision task were stressed. Participants assigned to the CA condition were also instructed to repeat aloud continuously and rapidly the alphabetical sequence of letters A through G throughout each block of the lexical decision task. Prior to any experimental trials, 10 lexical decision trials were completed in silence and without CA to familiarize participants with the task. Written instructions appeared on the screen prior to each block to inform them of the change in auditory stimuli and to remind participants in the CA

condition to vocalize the letters A through G. After completing both blocks of the lexical decision task, instructions appeared on screen to explain how the recognition checklist was to be completed and these instructions were identical to those used in Experiments 1 and 2 with the exception that participants in the CA condition were instructed not to articulate while completing the recognition checklist.

Following the surprise recognition task, participants completed the serial recall task. Participants were provided with two practice sets in silence (and without CA) prior to performing any experimental trials. Participants were informed that they would be presented with nine new random words on each trial and be required to rehearse the words for 10 seconds after the last word until the word “recall” appeared. They then immediately wrote down the words in the same order as presented. They were informed that 15 sets would be completed in silence, and 15 with changing-state tones, and that they should simply ignore the sounds. Participants assigned to the CA condition were also instructed to repeat aloud the alphabetical sequence of letters A through G continuously and rapidly during presentation of each set of nine words as well as during the ten second retention period, but not while recording the words on paper. Participants were informed that the irrelevant sounds would be the same as those from the surprise recognition task. After completion of the serial recall task, participants were debriefed and compensated.

Results

Lexical decision task.

Response time. For all RT measures, trials were included only if the item was identified correctly. Correct RTs were subjected to an outlier elimination procedure performed separately for each combination of participant, letter string (word/pseudo-word) and sound condition (silence or changing-state). Response times greater than three standard deviations from the mean were removed (fewer than 2% of all trials). A 2 (sound condition: silence versus changing-state) by 2 (item type: word versus pseudo-word) by 2 (CA versus no CA) mixed-model ANOVA was employed to examine RTs to visual lexical decision items. Sound condition and lexical item type were within-participant factors whereas CA was a between-participant factor. Results revealed a significant main effect of item type where RTs to words were 75ms faster than RTs to pseudo-words, $F(1, 71) = 60.71, p < .001$ (see Figure 9). A significant main effect for sound condition was also observed, $F(1, 71) = 11.17, p = .001$ where RTs under the changing-state conditions were 30ms faster than RTs under silence. The interaction between item type and sound condition approached significance, $F(1, 71) = 2.93, p = .091$, revealing a trend where pseudo-words showed a larger effect of irrelevant sound on RTs than did words. The main effect of CA also approached significance, $F(1, 71) = 3.90, p = .052$, such that RTs were a mean of 49ms slower for participants who engaged in CA than those who did not engage in CA. No other effects were statistically significant, all $ps > .10$.

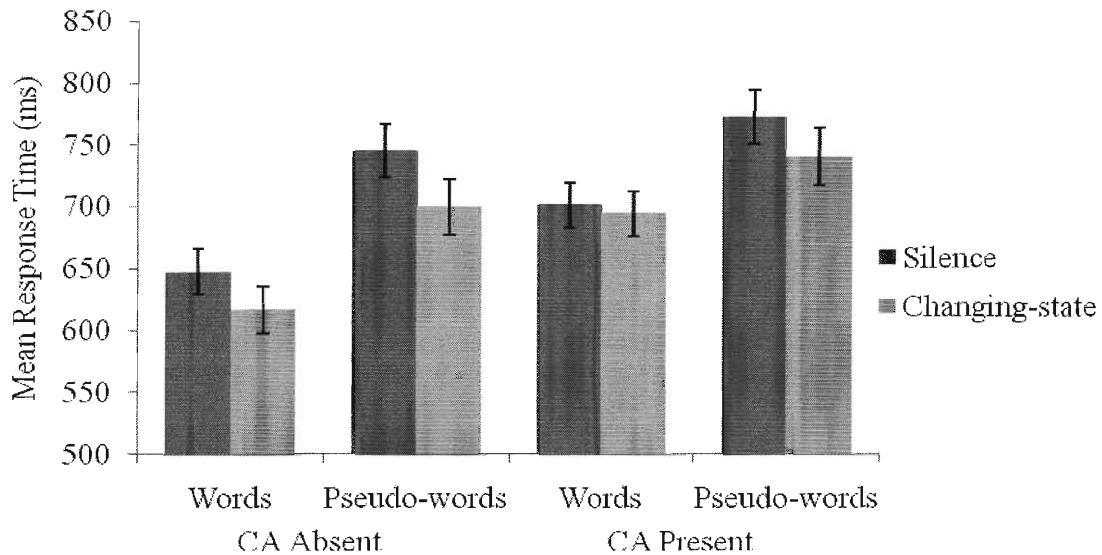


Figure 9. Mean Lexical Decision RTs in Experiment 3 as a function of lexical status, irrelevant sound condition and presence/absence of CA. Error bars represent the standard error for each mean.

Accuracy. The mean proportion of correct lexical decisions was submitted to a 2 (sound condition: silence versus changing-state) by 2 (lexical item type: word versus pseudo-word) by 2 (CA versus no CA) mixed-model ANOVA to investigate accuracy for visual lexical decision items during presentation of irrelevant auditory stimuli. Results indicated a main effect for item type, $F(1, 71) = 7.44, p = .008$, such that words were more identified more accurately than pseudo-words. A main effect for sound condition was also observed, $F(1, 71) = 8.95, p = .004$, such that accuracy scores were lower under conditions of changing-state irrelevant sound (see Figure 10 for means). No other effects, including those with CA, were significant, all $ps > .23$.

When examining the pattern of lexical decision RTs and accuracy, items presented with irrelevant sound showed faster RTs and reduced accuracy. This pattern

suggests the possibility of a speed-accuracy trade-off whereby the addition of irrelevant sound leads to careless or hurried performance in the lexical decision task.

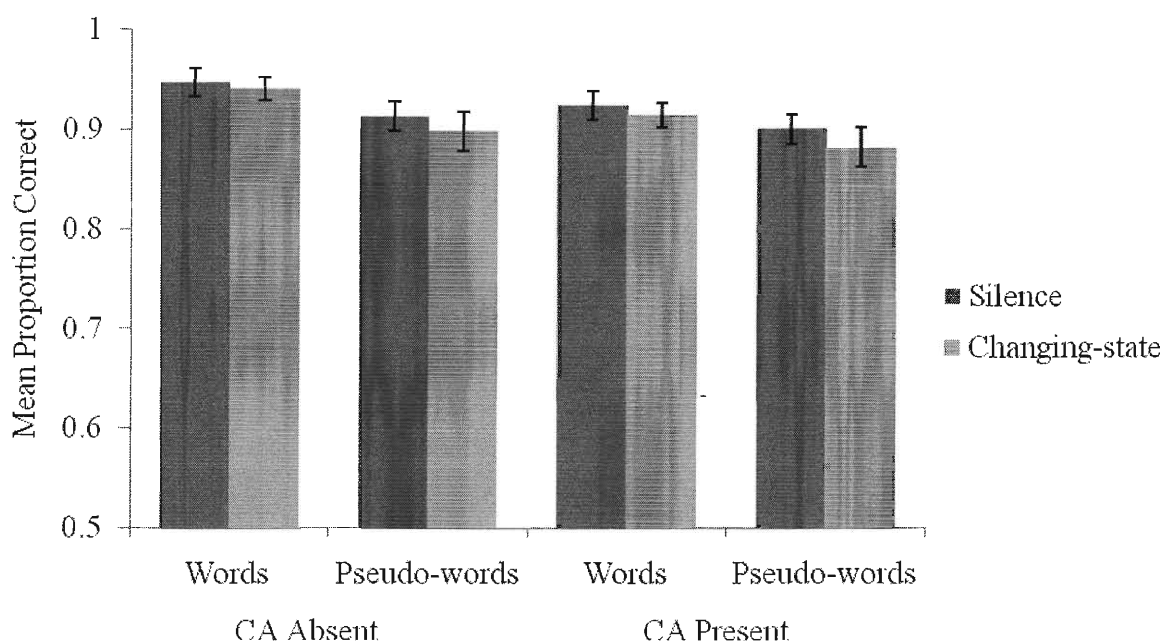


Figure 10. Mean Proportion Correct Lexical Decisions in Experiment 3 as a function of lexical status, sound condition and presence/absence of CA. Error bars represent the standard error for each mean.

Memory performance.

Surprise non-serial recognition. For each participant, memory sensitivity scores were calculated separately for words presented in silence and words presented with irrelevant changing-state tones (pseudo-words were not presented on the test list). Sensitivity scores were calculated by subtracting each participant's number of overall false alarms from their number of correct identifications on the checklist of words presented in each condition. This sensitivity score represents a participant's ability to differentiate old words (previously shown in the experiment) from new-at-test words. Across all participants, the grand mean sensitivity score was .48 (SD = .21).

Mean sensitivity scores were submitted to a 2 (sound condition: silence versus changing-state irrelevant sound) by 2 (CA versus no CA) by 9 (serial position) mixed-model ANOVA. A main effect for sound condition was observed, $F(1, 71) = 8.60, p = .005$, such that words presented under conditions of irrelevant changing-state sound were less likely to be reported than words presented during silence. Similarly, a main effect of CA was observed, $F(1, 71) = 22.87, p < .001$, such that items presented under conditions of CA were less likely to be reported. A main effect of serial position was also observed, $F(8, 568) = 4.29, p < .001$, such that items that fell towards the end of the to-be-remember list were more likely to be reported (see Figure 11). None of the interactions approached significance, all $ps > .16$. Planned-comparison t-tests showed significantly lower sensitivity scores for words presented with changing-state irrelevant sound compared to words presented in the silent control in the CA absent condition, $t(36) = 2.07, p = .046$. The same comparison made under conditions of CA showed a similar difference in sensitivity scores between the changing-state irrelevant sound condition and the silent control, $t(36) = 2.08, p = .044$.

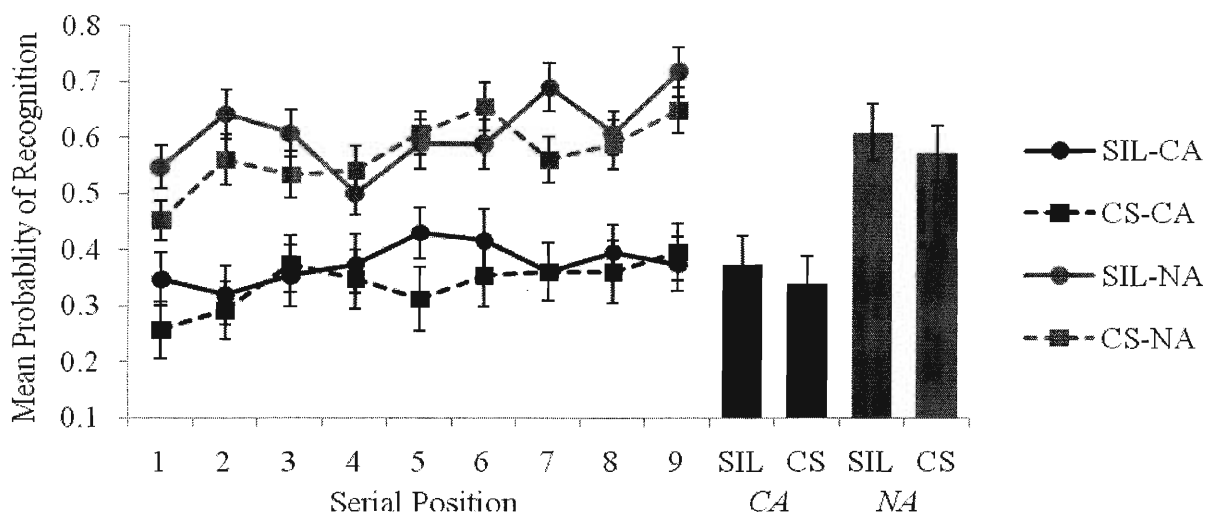


Figure 11. Memory performance on the surprise recognition memory test in Experiment 3. Lines represent mean probability of recognition as a function of sound condition, CA and serial position. Columns represent mean sensitivity scores for words as a function of irrelevant sound condition: silence (SIL) and changing-state irrelevant sound (CS); and concurrent articulation (CA) and no CA (NA). Error bars represent the standard error for each mean.

Serial recall (conservative scoring method). For each participant, serial recall scores were calculated separately for words presented in silence and words presented with changing-state irrelevant tones. For each trial, participants were given a score out of nine (nine words were presented per trial). A “point” was awarded for each word correctly recalled in the correct position. In this way, a strict rule was applied to the serial nature of the task: each word must be correctly reported in the correct serial position. Recall proportions were averaged across the 15 trials within each sound condition. Across all participants and conditions, the grand mean proportion of correct recalls was .26 (SD = .15).

Mean recall scores were submitted to a 2 (sound condition: silence versus changing-state irrelevant sound) by 2 (CA versus no CA) by 9 (serial position) mixed-model ANOVA. A main effect of serial position was observed whereby items presented at the beginning or the end of the 9-item set were more likely to be recalled, $F(8, 568) = 54.41, p < .001$ (see Figure 12). The main effect of sound, $F(1, 71) = 5.24, p = .025$, and the main effect of CA, $F(1, 71) = 27.02, p < .001$, were also significant whereby items that were presented under conditions of irrelevant changing-state sound or under conditions of CA were less likely to be reported. The interaction between serial position and CA was significant, $F(8, 568) = 2.14, p = .031$. Follow-up independent-samples *t*-tests performed separately for each sound condition at each position indicated that items presented under CA were significantly less likely to be reported at each position, all $ps < .036$, except for the comparison at position 9 in the changing-state irrelevant sound condition $t(71) = 1.76, p = .083$. No other effects, including the interaction between CA and sound condition, $F(1, 71) = 1.77, p = .188$, were significant, all $ps > .15$. Planned-comparison *t*-tests showed significantly lower recall scores for words presented with changing-state irrelevant sound compared to words presented in the silent control in the CA absent condition, $t(36) = 2.36, p = .024$. The same comparison made under conditions of CA showed no difference recall scores between the changing-state irrelevant sound condition and the silent control, $t(36) < 1$.

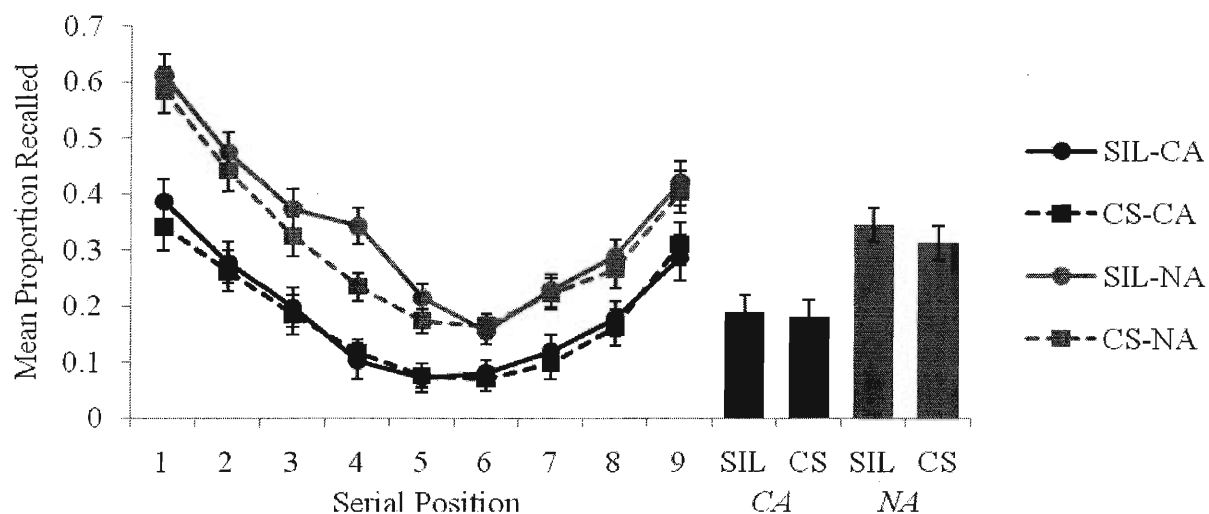


Figure 12. Memory performance in the serial recall task of Experiment 3. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition, CA and serial position. Columns represent mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL) and changing-state irrelevant sound (CS); and concurrent articulation (CA) and no CA (NA). Error bars represent the standard error for each mean.

Serial recall (scoring without order constraints). Using the same data gathered from the standard serial recall task, the more liberal scoring method, used in Experiment 2, was applied. For each participant, serial recall scores were calculated separately for words presented in silence and words presented with changing-state irrelevant tones. For each trial, participants were given a score out of nine (nine words were presented per trial). Using the liberal method, no restriction for order was imposed on the recall scores. A “point” was awarded for each word correctly recalled regardless of the order in which it was recalled. Recall proportions were averaged across the 15 trials within each sound

condition. Across all participants and conditions, the grand mean proportion of correct recalls was .37 (SD = .013).

Mean recall scores were submitted to a 2 (sound condition: silence versus changing-state irrelevant sound) by 2 (CA versus no CA) by 9 (serial position) mixed-model ANOVA. A main effect of position was observed whereby items presented at the beginning or the end of the 9-item set were more likely to be recalled, $F(8, 568) = 32.46$, $p < .001$. A main effect of sound was also observed, $F(1, 71) = 14.69$, $p < .001$, whereby items presented with irrelevant changing-state sound were less likely to be reported. A main effect of CA was also observed, $F(1, 71) = 25.06$, $p < .001$, such that items presented during CA were less likely to be reported (see Figure 13). The interaction between position and CA reached significance, $F(8, 568) = 2.84$, $p = .004$. Follow-up independent-samples t-tests performed separately at each position indicated that items presented under CA were significantly less likely to be reported than items presented without CA at each of the positions, all $ps < .05$, except for positions 7-9, all $ps > .05$. No other effects, including the interaction between CA and sound condition, were significant, all $ps > .14$. However, planned-comparison t-tests showed significantly lower recall scores for words presented with changing-state irrelevant sound compared to words presented with silence in the CA absent condition, $t(36) = 3.14$, $p = .003$, and this was also observed in the CA condition, $t(36) = 2.38$, $p = .023$.

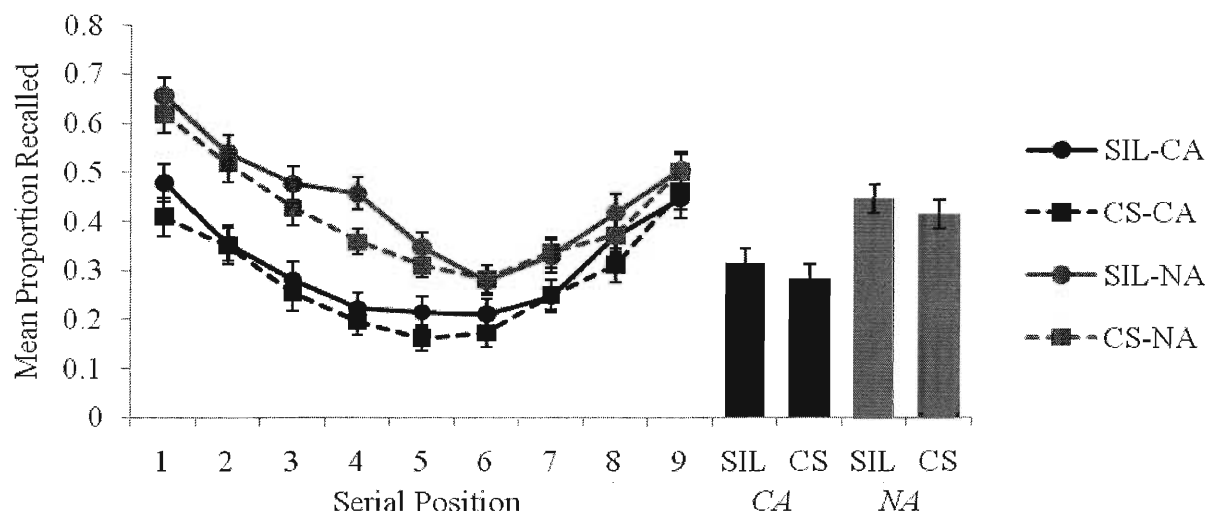


Figure 13. Memory performance in the serial recall task in Experiment 3 scored without regard for recall order. Lines represent the mean proportion of words recalled as a function of irrelevant sound condition, CA and serial position. Columns represent overall mean proportion of words recalled as a function of irrelevant sound condition: silence (SIL) and changing-state irrelevant sound (CS); and concurrent articulation (CA) versus no CA (NA). Error bars represent the standard error for each mean.

Summary of planned comparisons. As reported above, a series of six hypothesis-driven planned comparison t-tests was conducted to examine the ISE in the various conditions of Experiment 3. These paired-samples t-tests compare memory performance for silence versus changing-state conditions separately for both memory tasks and both CA conditions. A summary of these tests is provided in Table 1. Note that all comparisons are significant at the .05 level, except for the strict scoring measure of serial recall under conditions of CA. That is, the ISE was eliminated when participants engaged in CA in the standard serial recall task where correct order was scored.

	Task - Measure	CS	SIL	<i>t</i> (36)	<i>p</i>
NA	Surprise Non-serial Recognition - <i>Sensitivity Score</i>	.39 (.19)	.43 (.16)	2.07	.046*
	Serial Recall (Strict) - <i>Proportion Correct</i>	.31 (.12)	.34 (.14)	2.36	.024*
	Serial Recall (Liberal) - <i>Proportion Correct</i>	.41 (.09)	.44 (.11)	3.14	.003*
CA	Surprise Non-serial Recognition - <i>Sensitivity Score</i>	.13 (.30)	.17 (.31)	2.08	.044*
	Serial Recall (Strict) - <i>Proportion Correct</i>	.18 (.11)	.19 (.13)	.75	.457
	Serial Recall (Liberal) - <i>Proportion Correct</i>	.28 (.12)	.31 (.13)	2.38	.023*

Table 1. Mean (Standard Deviation) memory performance for each task and measure as a function of sound condition: changing-state (CS) or silence (SIL), and concurrent articulation (CA) or no CA (NA).

Discussion

The pattern of results in Experiment 3 provides compelling and straightforward evidence against the O-OER model (Jones, 1993). LeCompte (1994) first revealed a significant challenge to the O-OER model after finding an ISE with free recall, paired-associates, and recognition tasks. However, Beaman and Jones (1997) argued that even though the nature of the tasks used by LeCompte (1994) did not require or promote serial rehearsal, participants still knew they had to remember the items and so they may have serially rehearsed to-be-remembered items even when it was unnecessary to do so to succeed in the task. Beaman and Jones (1997) provided support for this assumption by demonstrating that CA eliminated the ISE even in these non-serial tasks. CA is thought to suppress the process of serial rehearsal by occupying the mechanism of phonological articulation of to-be-remembered items such that irrelevant sound cannot additionally interfere. The purpose of Experiment 3 was to determine whether CA eliminates the effect of irrelevant sound in the surprise non-serial recognition task which I contend does not rely on rehearsal or maintenance of order information.

It may be helpful to discuss the results of Experiment 3 in the order in which the field has developed. Historically, strictly serial recall tasks were used to examine the impact of irrelevant sound on memory. Success in serial recall tasks necessarily relies on rehearsal and the maintenance of order information. The serial recall task used here demonstrated the typical ISE result. When participants were not engaged in CA, which the majority of previous studies do not impose, serial recall performance was impaired under conditions of irrelevant changing-state sound relative to a silent control. In contrast, serial recall was not impaired by irrelevant sound when participants engaged in CA—the ISE disappeared. Note that this pattern mimics the pattern observed by Beaman and Jones (1997, Experiment 3b) whereby serial recall performance was not impaired by irrelevant speech when participants engaged in CA. Overall, serial recall performance was impaired by CA (c.f., Beaman & Jones, 1997), but performance was not further impaired by irrelevant sound. The magnitude of the ISE dropped from about 3% in the non-CA condition, to null in the CA condition. This was the hypothesized pattern for this task and was indeed predicted by Beaman and Jones (1997) who assert that the ISE is driven by a disruption of serial rehearsal processes. According to Beaman and Jones, CA occupies the rehearsal mechanism such that irrelevant sound is unable to further disturb rehearsal and impair serial recall. The results from Experiment 3 tentatively support this view.

However, the first result from Experiment 3 that diverges from the predictions of Beaman and Jones (1997), and the changing-state hypothesis, is that the ISE does not disappear with CA when serial recall performance is quantified using a liberal scoring

method. Using this method, successful recall is quantified without the restriction that the recalled item be reported in the correct serial position. This method approximates free recall, but differs in that instructions to participants are still to report items in the same order as presented. When serial recall was scored using this method, the ISE was nonetheless observed regardless of whether participants engaged in CA or not. Although performance was reduced overall by CA, the magnitude of the ISE (about 4%) remained unchanged relative to the non-CA condition. This pattern suggests that CA does impair rehearsal which maintains serial order information, so when recall performance for words presented while performing CA is scored for serial order correct, serial order information is poorly retained in both the silence and sound conditions, and no ISE is observed. However, CA does not impair the stimulus identity information, and when recall performance for words presented while performing CA is scored for without concern for correct order, the harmful effects of irrelevant sound on word identity information are revealed, and an ISE is observed, providing further evidence that the ISE does not rely on rehearsal or memory for serial order.

The results from the surprise non-serial recognition task provide the most compelling evidence against the changing-state hypothesis (Jones & Macken, 1993). The results from the surprise non-serial recognition task address Beaman and Jones's (1997) concern that serial order was still used in LeCompte's (1994) free recall and recognition tasks. As in Experiment 1 and Experiment 2, surprise non-serial recognition performance was impaired by irrelevant sound relative to a silent control condition. Critically, this performance difference (about 4%) was consistent whether participants engaged in CA or

not. Thus, in the surprise recognition memory task, CA did not abolish the ISE. Given that CA should eliminate the ISE in any task in which rehearsal or memory for order is the dominate strategy, and that the ISE was nonetheless observed in the surprise recognition memory task, we can now conclude that participants are not engaging in rehearsal during list exposure prior to the surprise non-serial recognition memory test. The repeated finding here of an ISE in the recognition memory task can now be used as evidence against the O-OER model as well as the changing-state hypothesis.

General Discussion

Before continuing, it may be beneficial to summarize the findings from all three experiments. Experiment 1 revealed that the ISE (impaired memory performance associated with the presence of irrelevant background sound relative to silence) can be observed in a surprise non-serial recognition task where rehearsal and maintenance of order information are very unlikely to be present. Experiment 2 tested for the ISE in the same surprise non-serial recognition task as Experiment 1, as well as a serial recall task. Memory performance was compared for changing-state and steady-state irrelevant sound conditions and silence. Experiment 2 showed that memory performance in the surprise non-serial recognition task was equally impaired by any form of irrelevant sound, whether changing-state (a sequence of randomly selected auditory tones) or steady-state (a single auditory tone repeated) relative to a silent control. No significant ISE was observed with either of the irrelevant tone conditions when the serial recall task was used. However, a trend for a small and equal ISE for both tone conditions was found in serial recall, but only when scored using a liberal scoring method which placed less emphasis

on the order of recall. Experiment 3 tested for the ISE under conditions of CA (repeated vocalization of the letters A through G), which was previously shown to eliminate the ISE in serial recall (Beaman & Jones, 1997). Experiment 3 showed that the ISE was indeed eliminated by CA in the serial recall task. However, when scored using a liberal scoring method, CA did not eliminate the ISE in serial recall. Results also showed that surprise non-serial recognition was immune to the influence of CA and revealed the ISE whether participants engaged in CA or not.

Implications for Models of the ISE

Several models have been proposed to account for the ISE, and some of these have been heavily influenced by the use of serial recall as the primary task. One such example is the prominent model of the ISE—the O-OER model (Jones, 1993). Critically, the O-OER model stresses that the memory impairment reflected in the ISE is based on the disruption of order information and serial rehearsal processes. Jones (1993) asserts that all stimuli, whether visual or auditory, automatically generate internally represented linkages, or pointers, that embody the order in which the to-be-remembered stimuli were presented. Because each source of information automatically produces its own linkages, relevant and irrelevant linkages may become confused with each other leading to perturbation of order information for the relevant information. Therefore, the O-OER model explains the ISE in terms of linkages generated by irrelevant material interfering with linkages generated by relevant material.

As a corollary of the O-OER model, the so-called *changing-state hypothesis* (Jones & Macken, 1993; 1995) states that the degree to which the irrelevant sound

changes in terms of physical and acoustic features is directly proportional to the amount of disruption in a serial recall task. The authors suggest that the seriation linkages or pointers that underlie the O-OER model underlie the relationship specified in the changing-state hypothesis. The quantity of pointers generated is directly proportional to the number of acoustic changes in the auditory stream. Jones and Macken (1993; 1995) suggest that because changing-state stimuli generate more pointers than steady-state stimuli (or silence) and are qualitatively more varied, they are thus more disruptive to serial recall because there are more opportunities for overlap of relevant and irrelevant linkages. According to the O-OER model and the changing-state hypothesis, any disruption associated with irrelevant sound should be observed only when participants rely on a strategy that specifically draws on the order information contained within these linkages.

The results of the present series of experiments conflict directly with these views. In a surprise non-serial recognition task in which neither rehearsal nor maintenance of order information was used, an ISE was nonetheless observed. This suggests strongly that the O-OER model cannot be a viable explanation of the ISE. Similarly, the changing-state hypothesis falls short of adequate explanation. The present series of results shows that any form of irrelevant sound, whether changing- or steady-state, can disrupt surprise non-serial recognition. An additional prediction made by the changing-state hypothesis is that CA should eliminate the ISE given that it apparently occupies the same mechanisms that are perturbed by irrelevant sound. Again, the present series of experiments shows that irrelevant sound still impairs surprise non-serial recognition

memory performance when participants engage in CA. If disruptions to rehearsal were all that mattered to explain the ISE, then no differences should have been observed between silence and changing-state tone conditions when CA was performed. However, both surprise recognition memory and the serial recall performance when order was not scored showed a significant ISE, both with and without CA. Instead, the evidence suggests that the ISE may perturb earlier processes of memory formation such as encoding. Even though participants are not aware of the impending memory test (e.g., participants do not engage rehearsal), this interference occurs whether the task is serial or non-serial.

Some alternative rehearsal-independent models such as the Feature Model proposed by Nairne (1990; extended by Neath, 2000) also fall short of adequate explanation. The Feature Model proposes that the ISE could be explained in terms of progressive occlusion of to-be-remembered stimuli based on overlap of common (acoustic) features between relevant and irrelevant stimuli (i.e., confusion of auditory feature information). Given that the verbal-lexical visual stimuli and non-speech auditory tones used here share few auditory features, the Feature Model is unable to account for the observed memory impairment.

Broadbent (1984) suggested an attentional model in which the ISE was said to result from a breakdown at an attention-demanding encoding stage where features of to-be-remembered items must be transformed into a conscious internal representation in working memory. According to this account, irrelevant sound impairs the ability to convert to-be-remembered items into the phonological code. Irrelevant changing-state auditory

items are given automatic access to this store (e.g., Salamé & Baddeley, 1982). Consequently, these irrelevant items are able to disrupt articulation into memory of relevant to-be-remembered items. Similar to the feature model (Nairne, 1990; Neath, 2000), this model superficially suggests that the phonological code itself is the locus of distraction. Additionally, Broadbent's use of the language of articulation, may have implicitly directed other researchers (e.g., Jones, 1993) to infer a rehearsal process. Rather, Broadbent (1984) may have placed the locus of distraction at the attention-demanding translation of visually presented items into internal (auditory) representations. Note that this process still posits a phonological representation that is susceptible to auditory interference, but in Broadbent's model this results from attentional distraction leading to a failure to encode the item in working memory.

Perhaps building on this notion, Cowan (1995, 1999) better articulates the process of attentional distraction in his embedded-processes model of working memory. This model suggests that representations held in the focus of attention are consciously and immediately available for use in working memory and that the cognitive locus of distraction lies in the redirection of the focus of attention away from the primary stimuli or task. Although the focus of attention is consciously and voluntarily controlled by a central executive (c.f., Baddeley & Hitch, 1974), it can be involuntarily attracted by personally relevant stimuli (e.g., Moray, 1959; Treisman, 1960) or changes in physical properties of an irrelevant stream of stimuli (Berti & Schröger, 2001; Escera et al., 1998; Johnson & Zatorre, 2005; Lange, 2005; Schröger 1997; Schröger & Wolff, 1998; for a review see Driver, 2001). Thus, if the focus of attention is attracted away from the to-be-

remembered items by irrelevant material, they will be less active in working memory or even absent from working memory. As a result, memory impairment should be observed.

Unlike the O-OER model (Jones, 1993), Cowan's (1995; 1999) embedded-processes model does not rely on a disruption of order information (e.g., seriation linkages) to explain memory impairment associated with irrelevant sound. Note also that Cowan's model does not rely directly on a disruption of rehearsal processes to explain the ISE. Rather, the model suggests that items held in the focus of attention at the moment of distraction lose their activation benefit and are subsequently only weakly represented in short-term (and long-term) memory. Thus, to the extent that the primary task involves the preservation of item information (e.g., for later recall), attention capture by irrelevant stimuli should reduce subsequent memory performance. In the case of a surprise recognition memory task where participants are unaware that the words are to be remembered, attention capture away from the primary task (e.g., lexical decision) results in a weaker working memory representation for the words. Thus, at the time of memory retrieval, these poorly encoded words are less likely to be recognized. Similarly, in the case of a serial recall task, attention capture away from the primary task still explains the memory impairment despite the added element of rehearsal. Note that attention-capture accounts (e.g., Broadbent, 1984; Cowan, 1995, 1999) can explain the ISE regardless of whether or not rehearsal is a component of the task. Indeed, the results from the serial recall task when it was liberally scored in Experiment 3 suggest that irrelevant sound may perturb item information independent of order information.

The present results suggest that it is necessary to move the locus of distraction back to the earlier process of encoding where the internal representation of a to-be-remembered item itself is perturbed in some way. The best explanation for the ISE is now much simpler: attention is diverted away from the primary task by irrelevant material such that task-relevant material receives fewer attentional resources. Whether the task is based on active encoding of material for later retrieval (e.g., serial recall) or something else altogether (e.g., lexical decision) does not matter. Any redirection of attention away from to-be-remembered material will lead to memory impairment for that material.

Attentional Distraction and Lexical Decision Performance

One possible criticism of the present results is that online measurements of lexical decision performance such as RT do not readily support a distraction-at-encoding hypothesis. Specifically, if irrelevant sound really did capture attention away from the primary task, why is there no clear pattern of increased lexical decision RTs in the tone conditions relative to the silent control? Indeed, as discussed in the Introduction, the expected pattern of RTs is present in the Deviation Effect paradigm where an irrelevant auditory deviant delays RTs for a primary visual task relative to when the visual task is performed with predictable irrelevant auditory stimuli (Hughes et al., 2005). One possibility is that the representation created for visually presented words paired with irrelevant sound is weaker (as postulated by Cowan, 1995), but that this weakened representation is nonetheless sufficient to allow unimpaired lexical decision performance, even though it cannot fully support recognition or recall performance. Given the nature

of the lexical decision task and the surprise memory test used in the present series of experiments, participants did not actively maintain item information; participants were simply concerned with categorization of visually presented material. If participants were in fact aware of the impending memory test, RTs may have been longer overall, and an RT cost associated with irrelevant sound may have been observed. In this case, a temporary shift of attention away from the primary task by irrelevant sound may be followed by a re-orienting of attention to the visual target to ensure full encoding. In other words, if participants are motivated to build a strong memory representation, then at some level, participants may recognize that a relatively weak representation has been constructed and may attempt to more strongly encode the perturbed item before making a button response. Further research using electrophysiological techniques may reveal cognitive markers signalling poorer encoding of material, attentional shifts, and re-orientation of attention (see Berti & Schröger, 2001) associated with irrelevant sound. It may also be theoretically useful to examine performance in the same task when participants are indeed aware of the impending memory test.

Disambiguating Identity and Order Information in Serial Recall

Typically, serial recall tasks are based on recall of 9-item lists of digits (e.g., Beaman & Jones, 1997) or letters (e.g., Colle & Welsh, 1976) where the same 9 items are used on every trial. Participants are either told, or rapidly come to learn, the identity of the items on each trial; thus the only errors that are observed are order errors. In this way, typical serial recall tasks isolate the impact of irrelevant sound on order information, not on identity information. However, in the present series of experiments, 9-item to-be-

remembered serial recall lists were comprised of words where each word was shown only once throughout the entire experiment. Thus, unlike previous studies where item identity is known, participants were responsible for maintaining both identity and order information in the serial recall tasks used here. It is possible that the absence of the ISE in the serial recall task of Experiment 2 and the relatively small, though significant, ISE observed in the serial recall task of Experiment 3 may be due to this increased task difficulty and the importance of maintaining both order and identity information. It is clear from the surprise recognition results of Experiments 1, 2, and 3, that an ISE can be observed without the maintenance of serial order information or rehearsal. It is also clear from existing studies that an ISE can be observed even when the content of each memory set is known and only order information needs to be maintained (e.g., the 9 item digit lists used by Ellermeier and Zimmer [1997] where each digit 1 to 9 was used once in each list or by Jones [1993] where each of seven consonants was used once in each list). These results suggest that identity alone, or order alone, are sufficient to produce the ISE effect. It is therefore somewhat puzzling why the need to maintain both order and identity information would result in a weak or absent ISE, unless this is simply too much to ask of the participant even without the irrelevant sound. In future examinations of the ISE, it will be useful to compare serial recall performance using finite lists of various lengths versus infinite lists to further unravel the relative importance of order information and item information. Nonetheless, the results from the surprise non-serial recognition task, which necessarily uses a non-finite list, still provide compelling evidence that perturbations of order information alone do not account for the ISE in its entirety.

From the discussion just above, one might wonder how an attentional encoding explanation such as Cowan's (1995) or Broadbent's (1984) could account for the ISE in a serial recall task where the identity of the items was fixed and known for each trial. One possibility is that irrelevant sound impairs both the attentional encoding of an item and its serial rehearsal, and that a surprise recognition task shows the former impairment whereas typical serial recall tasks with a fixed set of items reveal the latter impairment. Rather than invoking two models to separately account for the ISE in serial recall and surprise non-serial recognition tasks, a more parsimonious explanation would be that an impairment in attentional encoding by irrelevant sounds would impair the encoding of both order information and item identity. Indeed, models of attention such as Treisman's feature integration theory (e.g., Treisman & Gelade, 1980) assume that the encoding of an item into working memory for later awareness represents the combining of all of the item's features or attributes (e.g., colour, size, phonology, location in space and time etc.). Thus, visual items that failed to be encoded into working memory or that were coded only weakly under conditions of irrelevant sound would be expected to have lost or impaired feature *and* order information.

Implications for our Understanding of Bottom-up and Top-Down Processing

In general, the results of the present series of experiments suggests that despite heavy exertion of top-down control over the allocation of attentional resources to a primary task in the face of task-irrelevant material, bottom-up attention capture can nonetheless lead to subsequent memory impairments. An ISE was observed when using

a surprise recognition task, even under conditions of CA. This suggests that the ISE could be framed in terms of obligatory bottom-up attention capture.

Casting the ISE as an example of bottom-up attention capture would unite the ISE and the highly similar Deviation Effect (e.g., Hughes et al., 2005) with a common mechanism. The Deviation Effect is already explained in terms of bottom-up attention capture. The Deviation Effect is observed when a single irrelevant auditory deviant captures attention and impairs visual serial recall performance relative to recall performance for items presented with predictable auditory stimuli (e.g., Hughes et al., 2005). Hughes and colleagues (2005) observed serial recall deficits when to-be-remembered visual consonants were paired with irrelevant auditory digit streams that contained a temporal deviant, versus auditory streams with a constant inter-stimulus interval (items can also be defined as deviant based on acoustic properties such as pitch or timbre). The proposed mechanism of this Deviation Effect is a perturbation of the encoding process by redirection of attention such that the to-be-remembered item loses its activation benefit (e.g., Cowan, 1995, 1999). The Deviation Effect, defined as attention capture by a deviant irrelevant item, is thought to be distinct from the ISE (Hughes et al., 2005, 2007), and the Deviation Effect and the ISE have been considered as two separate phenomena. However, it is possible that both may be explained by the same mechanism. An item is defined as a deviant in terms of its mismatch with previous items; in the case of changing-state stimuli, each tone is qualitatively different from each of the preceding tones. Given that each subsequent tone is selected randomly, each tone thus deviates from the average of all previous tones and operates somewhat like a series of deviants. In

this way, the ISE observed with changing-state stimuli may be the average of several deviation effects across each trial. The present results help to bridge the theoretical gap between these phenomena by showing that the explanation for the Deviation Effect is consistent with what is now the best account of the ISE: perturbation of internal representations at encoding through bottom-up attention capture by task-irrelevant auditory stimuli. However, as discussed above, it is typical to observe on-line performance costs (e.g. longer RTs on the primary visual task) for deviants in the deviation effect, and yet these were not observed for the lexical decision RTs in any of the 3 experiments. More experiments will be needed to examine whether the Deviation Effect and the ISE are unrelated, related, or whether they are actually two versions of the same effect.

Serial Position Curves

Serial position curves from the serial recall tasks of the present set of experiments show clear primacy and recency effects, which indicates that participants were indeed doing a serial recall task. Interestingly, across all three experiments, when serial recall was quantified using a liberal non-serial method, the curve became flatter overall, suggesting that items have relatively equally strong internal representations across positions. The flattest curve (e.g., no primacy or recency effects) came from the surprise non-serial recognition tasks. This pattern should not be surprising given that rehearsal (said to drive the recency effect) was absent and participants were unaware of the memory tests so would not have employed any long-term storage strategies (said to drive the primacy effect; Oberauer, 2003).

Across a number of ISE studies, the data from serial position curves suggest that when the primary task is based strictly on serial recall, memory for items at position 1 is relatively unharmed by irrelevant speech or sounds. Memory disruption due to irrelevant sound becomes apparent only for mid and latter portions of the presentation list, and, despite a small overall recency effect, disruption due to irrelevant sound is still observed for the last list position (e.g., Colle & Welsh, 1976, Experiment 1). This pattern generally held true in the present series of experiments where serial recall performance was significantly impaired by irrelevant sound (i.e., Experiment 3) especially for words in the middle portion of the block. The absence here of a clear memory performance difference across the final few positions of a to-be-remembered serial recall set also confirms the speculative but suggestive result from LeCompte (1994) which suggests that rehearsal itself may be unharmed by irrelevant sound. Given that an equal recency effect (said to be driven by rehearsal) was observed for serial recall items regardless of whether irrelevant sound was present, it further supports the notion that rehearsal is not the (only) driving force of the ISE. Indeed, middle-position items appeared to suffer the most from irrelevant sound in serial recall in LeCompte's (1994) tasks as well as those presented here.

However, during the surprise non-serial recognition tasks, memory performance for words presented with irrelevant tones was equally impaired across all positions. The lack of a serial position curve in the surprise recognition task, and that the ISE was not limited to specific serial positions provides further evidence that participants were not engaging in serial rehearsal, and suggests that item representations are perturbed at

encoding rather than during rehearsal because items that would be active in memory if rehearsal were taking place are not more likely to be reported or less likely to succumb to the ISE than items that fall at other serial positions.

Final Summary

The present series of experiments demonstrates a significant challenge for the O-OER model (Jones, 1993) and the changing-state hypothesis (Jones & Macken, 1993) by showing that the ISE can be observed in a surprise recognition task in which participants are not rehearsing or relying on order information. This result was found consistently with both steady-state and changing-state irrelevant tones, and with and without the presence of CA. Instead of the O-OER model, a disruption-at-encoding account (Broadbent, 1984; Cowan, 1995, 1999) where item information is perturbed at the relatively early process of encoding is better able to account for the present data. The present series of experiments is the first, to my knowledge, to test for an ISE in a surprise non-serial recognition task, and this has been an important step toward understanding the nature of the ISE.

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(SWM), New Orleans, LA.

Appendix A. Research Ethics Board Approval Letter

FROM: Michelle McGinn, Chair
Research Ethics Board (REB)

TO: Karen ARNELL, Psychology

RE: Continuing Review

FILE: 04-138 - ARNELL

Original clearance date: January 25, 2005

Date of completion: August 31, 2010

DATE: April 27, 2009

Thank you for completing the *Continuing Review* form. The Brock University Research Ethics Board has reviewed this report for:

Attention Capture in RSVP

The Committee finds that your original proposal and ongoing research conforms to the Brock University guidelines set out for ethical research.

*** Continuing Review Accepted.**

Research Ethics Office

Brock University
Office of Research Services, MC D250A
500 Glenridge Avenue, St. Catharines, ON L2S 3A1
Phone 905-688-5550 ext. 3035
Fax 905-688-0748
Email: reb@brocku.ca
http://www.brocku.ca/researchservices/Ethics_Safety/Humans/Index.php

Appendix B. Consent Form

Informed Consent

Project Title: **Attention and Word Reading IV**

Principal Investigator:
Kirk Stokes ks03xo@brocku.ca
Department of Psychology
Brock University

Faculty Supervisor:
Dr. Karen Arnell karnell@brocku.ca
Associate Professor
Department of Psychology
Brock University

INVITATION

You are invited to participate in this research study of attention and cognition. The purpose of this study is to investigate your ability to process cognitive information quickly. In order to participate, you must have normal or corrected-to-normal (e.g., glasses, contacts) vision and you must have learned English before the age of 9.

WHAT'S INVOLVED

As a participant, you will be asked to identify words and non-words, and answer two brief questionnaires. We will measure your Reaction Time and accuracy on these tasks. Participation will take no more than 60 minutes of your time. You will receive either \$10 or 60 minutes of "course participation".

POTENTIAL BENEFITS AND RISKS

You may experience mild fatigue while performing trials. However, you may take a break at any point during the experiment.

CONFIDENTIALITY

All information you provide is considered anonymous and confidential; your name will not be included or associated in any way with the data collected in the study. Furthermore, because our interest is in the average responses of the entire group of participants, you can not be identified in any written reports of this research. The researchers have no way of identifying individual data.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. However, due to the anonymous nature of the experiment, data cannot be withdrawn once submitted.

PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at research conferences. The results of the study may be publicly presented at the Canadian Society for Brain, Behaviour, and Cognitive Sciences or other university Conferences in spring/summer 2010. All interested parties are encouraged to attend.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact the Principal Investigator listed above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (REB #04-138). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Thank you for your assistance in this project. Please keep a copy of this form for your records.

Informed Consent

Project Title: **Attention and Word Reading IV**

I agree to participate in the study described above. I have made this decision based on the information I have read in the Information Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: _____

Signature: _____ Date: _____

Compensation

I am participating in this study to receive **\$10**. I understand that I will not be able to use my participation in this study as the basis for an in-course assignment.

Signature: _____

Researcher Signature: _____

Or

I am participating in this study in order to use my participation as the basis for an in-course assignment in a course that utilizes this type of project in its curriculum (e.g, PSYC1F90). I understand that I will not receive cash payment for my participation in this study.

Signature: _____ Course: _____ Duration: 60 minutes

Researcher Signature: _____

Appendix C. Pool of words used in non-serial recognition and serial recall tasks.

ACHE	BREATH	CLOUD	DECK	FIND
AISLE	BREEZE	CLOVE	DEED	FIRM
ARCH	BRICK	CLOWN	DEEP	FISH
AUNT	BRIDGE	CLUB	DEER	FLAG
BACK	BRIEF	CLUE	DENT	FLAME
BADGE	BRIM	COACH	DESK	FLARE
BAIL	BROIL	COAL	DIME	FLASH
BAND	BRONZE	COAST	DIRT	FLEA
BANK	BRUSH	COCK	DISC	FLEECE
BARN	BUMP	COLD	DITCH	FLEET
BASE	BUSH	CONE	DIVE	FLESH
BASS	CAGE	COOK	DOCK	FLOAT
BATH	CALF	COOL	DOLL	FLOCK
BEACH	CALL	CORD	DOME	FLOOD
BEAK	CALM	CORE	DOOR	FLOOR
BEAM	CAMP	CORK	DOUGH	FLUSH
BEAN	CANE	CORN	DOVE	FLUTE
BEAR	CAPE	CORPS	DRAIN	FOIL
BEAST	CART	CORPSE	DRAW	FOOD
BEECH	CASE	COUCH	DREAM	FOOL
BEEF	CAST	COUNT	DRESS	FOOT
BELL	CELL	COURSE	DRINK	FORK
BELT	CENT	COURT	DROVE	FORM
BIRCH	CHAIN	CRAB	DRUG	FORT
BIRD	CHAIR	CRAFT	DRUM	FOUL
BIRTH	CHALK	CRANE	DUCK	FOWL
BLOCK	CHARM	CRANK	DUSK	FRAME
BLOUSE	CHART	CRAWL	DUST	FRIEND
BLUE	CHEEK	CREAM	EARTH	FRILL
BLUSH	CHEST	CREW	EAST	FROG
BOIL	CHIEF	CRIME	EDGE	FRONT
BOMB	CHILD	CROSS	EIGHT	FROST
BOND	CHINK	CROW	FACE	FROWN
BONE	CHOP	CROWD	FAINT	FRUIT
BOOK	CHROME	CROWN	FAIR	FUDGE
BOOT	CHURCH	CRUMB	FALL	FUSE
BOOTH	CLAW	CRUSH	FARM	GATE
BOWL	CLAY	CURB	FEAST	GEESE
BRAIN	CLEAN	CURE	FEET	GERM
BRAKE	CLIFF	CURSE	FELL	GHOST
BRANCH	CLINK	CURVE	FELT	GIFT
BRASS	CLOAK	DANCE	FENCE	GIRL
BRAT	CLOCK	DART	FILE	GLARE
BREAD	CLOSE	DATE	FILL	GLASS
BREAK	CLOTH	DEBT	FILM	GLEAM

GLOBE	HIVE	LIFT	NAIL	PLUM
GLOOM	HOLD	LIGHT	NAME	POINT
GLOVE	HOLE	LIMB	NECK	POLE
GOAL	HOME	LIME	NERVE	POLL
GOAT	HOOD	LINE	NEST	POND
GOLD	HOOF	LINK	NEWS	POOL
GOLF	HOOK	LINT	NIGHT	POPE
GRAPE	HORN	LOAD	NOSE	PORCH
GRAPH	HORSE	LOAN	NOTE	PORE
GRASS	HOSE	LOCK	NOUN	PORT
GRATE	HOUND	LODGE	NURSE	POST
GRAVE	HOUSE	LONG	OUNCE	POUR
GRAY	HOWL	LOOK	PAGE	PRAISE
GREEN	HURT	LOOP	PAINT	PRIEST
GRIND	HUSH	LORD	PAIR	PRIME
GRIP	INCH	LUNCH	PALM	PRINCE
GROUND	ISLE	LUNG	PANE	PRIZE
GROUP	ITCH	LURE	PANTS	PROP
GROVE	JAIL	MAIL	PARK	PRUNE
GROWTH	JEEP	MANE	PASS	PULL
GUARD	JOKE	MARCH	PASTE	PUMP
GUEST	JOLT	MASH	PEACH	PUNCH
GUIDE	JUDGE	MASS	PEAL	PURSE
GULF	JUICE	MAST	PEAR	QUACK
HAIL	JUMP	MATCH	PEARL	QUAIL
HAIR	KILT	MAZE	PECK	QUAKE
HALF	KING	MEAL	PEEL	QUEEN
HALL	KITE	MEAT	PEER	QUILL
HAND	KNEE	MILE	PELT	QUILT
HARE	KNIGHT	MILK	PERCH	RACE
HARP	LAKE	MINCE	PHASE	RACK
HAWK	LAMB	MINE	PHONE	RAID
HAZE	LAMP	MINK	PIECE	RAIL
HEAD	LAND	MISS	PIER	RAIN
HEALTH	LANE	MIST	PILE	RAKE
HEAP	LARD	MOAT	PILL	RAMP
HEART	LAUGH	MOLD	PINE	RANCH
HEAT	LAWN	MOLE	PINT	RANGE
HEDGE	LEAD	MOON	PIPE	REACH
HEEL	LEAF	MOOSE	PLAIN	REAR
HEIGHT	LEAK	MORGUE	PLAN	REED
HEIR	LEAN	MOSS	PLANE	REEL
HELL	LEAP	MOTH	PLANT	RENT
HERB	LEASE	MOUSE	PLATE	REST
HIDE	LENGTH	MOUTH	PLAY	RHYME
HILL	LENS	MOVE	PLOT	RICE
HIND	LIFE	MULE	PLUG	RIDGE

RIGHT	SHOE	SOUND	STREET	TRAY
RING	SHOOT	SOUP	STRING	TREAT
RISE	SHOP	SPACE	STRIPE	TREE
ROAD	SHORE	SPADE	STUMP	TRIBE
ROCK	SHORT	SPAN	STUNT	TRICK
ROGUE	SHOW	SPEAR	SUIT	TRIM
ROLL	SHRIMP	SPECK	SURF	TRIP
ROOF	SHRUB	SPEECH	SWAMP	TROOP
ROOM	SHRUG	SPELL	SWARM	TROUT
ROOT	SIDE	SPHERE	SWEAT	TRUCK
ROSE	SIGH	SPICE	SWEET	TUBE
ROUGH	SIGHT	SPIKE	SWELL	TUNE
ROUND	SIGN	SPLIT	SWIM	TURN
ROUTE	SILK	SPOKE	TAIL	TWIG
RUSH	SITE	SPONGE	TALK	TWIST
RUST	SIZE	SPOOK	TANK	TYPE
SAFE	SKATE	SPOOL	TAPE	VANE
SAGE	SKIN	SPOON	TASK	VASE
SAIL	SKIRT	SPOUT	TASTE	VAULT
SALE	SKULL	SPRAY	TEAM	VEAL
SALT	SKUNK	SPRING	TEAR	VEIL
SASH	SLANG	SPRINT	TENT	VEIN
SAUCE	SLAP	SPRUCE	TERM	VEST
SCALE	SLEEP	STAFF	TEST	VICE
SCENE	SLEET	STAIN	THEFT	VIEW
SCENT	SLEEVE	STAIR	THICK	VINE
SCHOOL	SLICE	STAND	THIEF	VOICE
SCOUT	SLIDE	STAR	THING	VOLT
SCROLL	SLIP	STARCH	THORN	VOTE
SEAL	SLOPE	STARE	THREAD	WAGE
SEAM	SLUSH	STATE	THUMB	WAIST
SEARCH	SMALL	STEAK	TIDE	WALK
SEAT	SMELL	STEAL	TILL	WALL
SEED	SMILE	STEAM	TOAD	WAND
SELF	SMOKE	STEEL	TOAST	WARE
SHALE	SNAIL	STEM	TOIL	WASH
SHAPE	SNAKE	STEP	TOLL	WASTE
SHAWL	SNEEZE	STEW	TOMB	WATCH
SHEAR	SNOW	STICK	TONGUE	WAVE
SHED	SOAP	STILL	TOOL	WEALTH
SHEEP	SOCK	STONE	TOOTH	WEAR
SHEET	SOFT	STOOL	TOUCH	WEED
SHELL	SOIL	STORE	TOWN	WEEK
SHIELD	SOLE	STORM	TRACK	WEIGHT
SHIP	SONG	STOVE	TRAIL	WELL
SHIRT	SOOT	STRAND	TRAIN	WEST
SHOCK	SORE	STRAW	TRASH	WHALE

WHEAT
WHEEL
WHIP
WHIRL
WHITE
WILD
WIND
WINE
WING
WINK
WOLF
WOMB
WOOD
WOOL
WORK
WORLD
WORM
WOUND
WRAP
YARD
YAWN
YEAR
YOUTH
ZONE

Appendix D. Pool of pseudo-words used in non-serial recognition task.

ANES	DETE	HAKE	NAXE	SCOD	TORP
ALDS	DIRL	HAWM	NEME	SEBS	TRAD
ARNO	DOLD	HEBE	NIET	SERN	TRAPE
BAFT	DOOTH	HEDE	NINK	SHING	TREWN
BAGES	DRAL	HEEM	NOKE	SIFE	TRING
BAME	DRET	HEWT	NOOT	SKAP	TROLK
BAST	DROOD	HINE	NUMT	SKINE	TROON
BAUNT	DRUNT	HOBE	NOLK	SKON	TRUD
BEBON	DUNT	HORT	OSTS	SKUBB	TRULP
BIAN	FALP	HORPE	PABS	SLEAR	TULT
BIANT	FAMS	HULD	PAGIC	SLOM	MUNT
BLAD	FETS	HULT	PATAL	SMARE	VACK
BLADS	FIPE	HUST	PEEM	SMID	VARD
BLETH	FLANG	HUFT	PELE	SNAB	VAYE
BLOM	FLARK	HUYE	PELCH	SONK	VORT
BLOOF	FLOAM	JARN	PERST	SORTH	VURM
BLUNK	FLOTH	JARP	PESE	SPAFE	WABE
BORP	FODE	KAGS	PHANK	SPALE	WALP
BRAIT	FOMP	KILP	PHOD	SPARL	WHAR
BRELK	FOOP	KIRP	PIME	STAIF	WILP
BRELL	FOWT	KULL	PITAN	STEEF	WOLT
BRONG	FRID	KURTS	PLAWD	STERP	WOTS
BROT	FRIMP	LADE	PLINS	STIEK	WRASE
BRUCK	FROUT	LANT	PLOAM	STOD	WRELN
BRYE	FUPE	LEART	PLUN	SUND	WRENK
BRYER	GATS	LIRD	POAN	SWARK	WUNK
BUME	GATH	LIRGE	POSK	TAFE	YOARN
BURK	GAST	LISE	PRAG	TAGE	YOUSH
CALT	GEBE	LIXE	PREST	TEAST	YUBE
CHERK	GERB	LOOD	PRILL	TELP	ZALL
CHUD	GLAST	LORF	PRON	TEBS	ZEEP
CLAID	GLEAT	LOWED	PRUT	TEDE	
CLENK	GLIM	LUFT	QUEED	THACK	
CLOM	GOGI	LULE	QUESS	THADE	
CLUVE	GOOM	MAFF	QUETH	THELT	
CADE	GORT	MALM	RART	THEND	
CORTH	GOST	MEAR	RAST	THIRP	
COUST	GOW	MESK	REGS	THIST	
CROLK	GRAGS	MERT	RETE	THRAT	
CROSP	GRALT	METE	RINAL	TIBE	
CROT	GRAME	MING	RITS	TIMAN	
CRULT	GROLT	MINOL	ROP	TOAFT	
DALSE	GRONK	MORL	RUFT	TOLP	
DALT	GRUT	MOSTY	RULL	TOLG	
DEAWN	GUBE	NARSE	SANN	TOOP	